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Enlarged twice

THE MILKY WAY NEAR THE TAIL OF THE SCORPION

R. A. 17 hours 50 minutes; S. D. 35°. Exposure 3 hours; 6-inch portrait lens.

Lick Observatory E. E. BARNARD

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

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ON THE SPECTROSCOPIC BINARY α^1 GEMINORUM.

By A. Bélopolsky.

My first photographs of the spectrum of this star (mag. 3.4, or, according to O.Σ, 3.7) were obtained for April 7 and 11, 1894, with the two-prism spectrograph of the Pulkowa Observatory mounted on the 30-inch equatorial. The two velocities in the line of sight, which I derived from the measurements by Vogel's first method (the star belongs to the same class as Sirius), differed by an amount which greatly exceeded the probable error of observation.

As I then suspected that the stars α^1 and α^2 Geminorum had been observed on the two nights, and not α^1 alone, but had no opportunity at that time to repeat the observations, the question whether the different velocities were real or not had to remain undecided.

It was not until January of the present year that I was able to resume the investigation, and I then found that my conjecture that the star is a binary was confirmed by thirty-two spectrograms, obtained between January 1 and April 26. In this connection I may remark that the spectra of α^1 and α^2 Geminorum are so different that one cannot possibly be mistaken for the other.

The exposure to the star was one hour; in the middle of the exposure the comparison spectrum of hydrogen was photo-

graphed. The star spectrum contains, besides the very broad hydrogen lines, all the stronger lines of iron, a circumstance which increases the certainty of the measurements. Using all the available material in the most careful manner possible[1] I obtained a series of values for the velocity of the star in the line of sight, and these values, after reduction to the Sun, exhibited a periodical change having a period of about 2.9 or 3.0 days. A closer approximation to the period was obtained by a consideration of the times at which the observed velocities in the line of sight were nearly zero. Such times are:

Pulkowa Mean Time			Velocity
1896.	February	$24^d.418$	$+1^{km}.3$
	"	27 .367	−0 .9
	March	8 .363	0 .9
	"	11 .321	+2 .7
	"	30 .350	+1 .7

Here it is necessary to take into account the fact that on February 24 and 27 and March 30 the velocities are increasing (changing from negative to positive values), and on March 8 and 11 decreasing. A short computation then gives for the actual times of zero velocity the following:

1896.	February	$24^d.399$	Pulkowa M. T.
	"	27 .379	
	March	8 .375	
	"	11 .358	
	"	30 .326	

Comparing those times which are separated by the shortest intervals (February 24 and 27, March 8 and 11) we obtain a period of 2.98 days; on the other hand, the period obtained from the dates February 24 and March 30, February 27 and March 30, is 2.91 days. I have used the latter value in computing the times of zero velocity, which are:

$$1896, \text{ February}, 27^d.34 + 2^d.91\, n,$$

where n is a whole number.

A provisional curve of velocities showed that the times of periastron passage occur $1^d.47$ later than the times of zero velocity.

[1] *Bull. Acad. St. Pétersburg*, December 1896.

In the following table are given, for each spectrogram obtained, the time at the middle of the exposure, the time of the nearest preceding periastron passage, the interval between this time and that of the observation, and finally the velocity reduced to the Sun.

LIST OF SPECTROGRAMS OF α[1] GEMINORUM.

Number	Date of Obs., 1896. Pulkowa M. T.	Periastron Passage, Pulkowa M. T.	Interval	Velocity relative to Sun
1	Jan. $1^d.43$	Dec. $29^d.70$	$2^d.73$	$-26^{km}.8$
2	20 .45	Jan. 19 .07	1 .38	−20 .6
3	Feb. 7 .43	Feb. 5 .53	1 .90	+22 .3
4	15 .45	14 .26	1 .19	+ 5 .6
5	19 .44	17 .17	2 .27	−18 .6
6	22 .42	20 .08	2 .34	+ 6 .2
7	23 .42	22 .99	0 .43	−33 .7
8	24 .42	22 .99	1 .43	+ 1 .3
9	25 .33	22 .99	2 .34	−16 .0
10	26 .36	25 .90	0 .46	−45 .4
11	27 .37	25 .90	1 .47	− 0 .9
12	Mar. 8 .36	Mar. 5 .63	2 .73	+ 0 .9
13	9 .32	8 .54	0 .78	−37 .9
14	11 .32	8 .54	2 .78	+ 2 .7
15	14 .38	14 .36	0 .02	− 9 .5
16	16 .33	14 .36	1 .97	+26 .1
17	17 .35	17 .27	0 .08	−38 .1
18	24 .38	23 .09	1 .29	−25 .7
19	30 .35	28 .91	1 .44	+ 1 .7
20	31 .36	28 .91	2 .45	+28 .5
21	Apr. 1 .36	31 .82	0 .54	−45 .0
22	3 .36	31 .82	2 .54	+22 .6
23	7 .36	Apr. 6 .64	0 .72	−40 .1
24	8 .36	6 .64	1 .72	+ 8 .6
25	11 .34	9 .55	1 .79	+ 7 .3
26	14 .35	12 .46	1 .89	+15 .9
27	17 .45	15 .37	2 .08	+17 .5
28	19 .39	18 .28	1 .11	−31 .3
29	20 .39	18 .28	2 .11	+20 .3
30	22 .41	21 19	1 .22	−16 .5
31	24 .45	24 .10	0 .35	−47 .6
32	26 .40	24 .10	2 .30	+34 .7

With these values I constructed the curve of velocity, by taking the figures in the fourth column for abscissæ and those in the last column for ordinates. The scale was chosen so that 2 units = 1 geographical mile[1] (= 7.42 kilometers), 10 units

[1] In accordance with the practice of this JOURNAL (3, 1–3, 1896) the German geographical miles used by Herr Bélopolsky have been changed to kilometers, except

= 1 day. It is at once apparent that the curve can be drawn either through the points No. 7, 1, 2, 4, 3, 5, 6, 9, or through all the remaining twenty-four points. A single curve cannot be drawn at once which will satisfy all the observations. Leaving the eight points out of consideration, and drawing through the others a curve which fulfils certain known conditions,[2] we obtain the following results:

Motion of the system relative to Sun $= 1^{\text{g.m}}.06 = -7^{\text{km}}.9$

Area bounded by curve, maximum ordinate and axis of abscissæ; $z_1 = +1010$ units (diminishing velocity), and $z_2 = -1575$ units (increasing velocities) $z_1 - z_2 = 2585 + 7$.

Greatest positive ordinate, $A = 10.46 = 5^{\text{g.m}}.23 = 38^{\text{km}}.8$.

Greatest negative ordinate, $B = 10.94 = 5^{\text{g.m}}.47 = 40^{\text{km}}.6$.

Let u_1, u_2 = the longitudes of those points on the orbit for which the velocity in the line of sight = 0,

ω = longitude of the periastron,

e = eccentricity,

$\left(\frac{dz}{dt}\right)$ = velocity in the line of sight at the time of periastron passage,

T = time of periastron passage,

$2a$ = major axis,

i = inclination,

μ = mean motion,

U = period, so that $\mu = \frac{2\pi}{U}$.

The following formulæ are used in the computation:

$$\sin u_1 = \frac{2\sqrt{AB}}{A+B}, \quad \cos u_1 = \frac{A-B}{A+B},$$

$$e \sin \omega = \sin u_1 \frac{z_2 + z_1}{z_2 - z_1}, \quad e \cos \omega = \cos u_1,$$

$$\left(\frac{dz}{dt}\right) = \frac{A+B}{2}(1+e)\cos \omega,$$

T is the abscissa corresponding to $\left(\frac{dz}{dt}\right)$.

$$a \sin i = 43{,}200 \frac{A+B}{\mu}\sqrt{1-e^2}.$$

in parts of the paper relating to the graphical construction, where a change of units did not seem to be desirable. Eds.

[2] R. Lehmann-Filhés, A. N., 3242, 136, 16–30.

The ephemeris was computed by means of the following formulæ:

$$\frac{dz}{dt} = \frac{A+B}{2}\cos u + \frac{A-B}{2}.$$

$$\mu\,(t-T) = E - e\sin E.$$

$$\tan\frac{u-\omega}{2} = \sqrt{\frac{1+e}{1-e}}\,\tan\frac{E}{2}.$$

The values obtained are:

$$A+B = 21.40 \qquad z_2 + z_1 = -\ 565$$

$$A-B = 0.48 \qquad z_2 - z_1 = -\ 2585$$

$$2\sqrt{AB} = 21.40$$

$$u_1 = 88^\circ.7 \qquad \left(\frac{dz}{dt}\right)_1 = -\ 0^{g.m}.7 = -\ 5^{km}.2$$

$$\omega = 96^\circ.0 \qquad T = +\ 0.01 \text{ day.}$$

$$e = 0.22 \qquad a\sin i = 837{,}000 - 418{,}500^{\,g.m} = 3{,}105{,}000^{km}.$$

The periastron passage occurs on

1896, February 28.82 ± 2.91*n*.

If, with these elements, we compute the motion in the line of sight at the times of observation, we obtain the following table:

Number	u	$\frac{dz}{dt}$	Curve	Obs. + $7^{km}.9$
20.	13 .8	+37^{km}.6	+39^{km}.0	36^{km}.4
22.	27 .0	+34 .5	+37 .5	+30 .5
12.	59 .2	+19 .3	+22 .7	— 8 .8
14.	68 .6	+13 .7	—15 .3	+10 .5
15.	98 .0	6 .4	— 8 .8	— 1 .6
17.	110 .0	14 .5	—18 .8	—30 .3
31.	159 .0	—37 .9	—38 .9	—39 .7
21.	186 .6	—40 .3	—40 .0	—37 .1
23.	208 .4	—35 .8	—36 .7	—32 .4
13.	215 .2	—33 .5	—35 .2	—30 .1
28.	246 .6	—16 .6	—19 .2	—23 .4
30.	255 .8	—10 .6	—12 .2	— 8 .6
18.	261 .6	— 6 .7	— 8 .0	—17 .0
19.	274 .0	+ 1 .9	+ 2 .5	+ 9 .6
24.	297 .0	—17 .1	+16 .8	— 16 .5
25.	303 .9	+20 .7	+20 .9	+15 .1
26.	311 .9	+25 .6	+26 .3	+23 .7
16.	319 .2	—29 .2	—30 .1	+34 .0
27.	329 .8	33 .4	+34 .6	— 25 .4
29.	332 .8	+34 .4	+35 .3	+28 .2
32.	354 .2	—38 .6	—39 .0	—42 .5

The points which were not used seem to form a group by themselves, and not to correspond at all to this curve. Only the points 8, 10, and 11 lie near it, while 3 has such a position that the curve is occasionally satisfied.

The cause of this discrepancy is probably that (as has already been remarked) the period 2.91 days cannot be used throughout the whole time covered by the observations. Hence a correction must be applied to the abscissæ of the points 7, 2, 4, 3, 5, 6, 9, and 1, and then a new curve drawn through these and the points previously considered.

The correction desired can be obtained graphically from the first curve. It is $0^d.32$. The corrected abscissæ are therefore:

1.	$3^d.05$	7.	$0^d.75$
2.	1 .70	8.	1 .75
3.	2 .22	9.	2 .66
4.	1 .51	10.	0 .78
5.	2 .59	11.	1 .79
6.	2 .66		

With these values we obtain:

Motion of system relative to Sun $= -1^{g.m.}.40 = 10^{km}.4$

$z_1 = + 951$ $\quad A = 10.3 = 5^{g.m.}.15 = 38^{km}.2$

$z_2 = - 1470$ $\quad B = 10.00 = 5^{g.m.}.00 = 37^{km}.1$

$e = 90^\circ.9$ $\quad \left(\frac{dz}{dt}\right) = - 0^{g.m.}.8 = - 5^{km}.9$

$\omega = 94^\circ.0$ $\quad T = 0.07$

0.21 $\quad a \sin i = 794,000 = 397,000^{g.m.} = 2.946.000^{km}$.

The epoch of periastron passage is

1896, February, $27^d.74 + 2.91n$.

The following velocities have been computed with the aid of these elements:

No.	[illegible]	[illegible]	Curve	Obs. – Curve
1	131 .8	$25^{km}.7$	$26^{km}.8$	$10^{km}.4$
[illegible]	3[illegible] .4	+18 .5	17 .8	+31 .0
[illegible]	353 .2	3[illegible] .0	+37 .5	+32 .7
4	284 .4	+ 8 .8	7 .8	10 .0

No.	u	$\frac{dz}{dt}$	Curve	Obs. − 10km.4
5.........	47.3	+25.1	28.9	29.0
6........	59.6	−18.5	+20.8	16.5
7........	270.4	−26.6	−30.1	23.3
8......	305.0	+21.1	−20.0	+11.7
9........	59.6	18.5	−21.5	+26.4
10......	220.6	−29.2	−28.9	−35.0
11....	308.4	−22.8	22.3	+9.5
12........	72.8	−10.6	+14.1	+11.3
13........	220.6	−29.2	28.9	27.5
14.......	82.4	+4.4	−5.9	13.1
15......	111.4	14.3	16.3	+0.9
16..........	325.4	+30.5	−30.1	+36.5
17..........	123.0	−21.1	−24.1	−27.8
18....	266.2	−3.1	−3.7	−15.4
19........	278.6	+5.0	5.2	−12.4
20..........	24.8	+33.6	+36.4	+38.9
21..........	103.8	−37.2	−36.0	−34.6
22........	38.8	+28.8	+31.5	+33.0
23....	214.4	31.8	31.2	29.8
24....	302.6	−19.7	−19.3	−19.0
25....	308.4	+22.8	+21.9	17.7
26.....	317.8	+27.4	26.7	+26.3
27........	337.0	+34.1	34.1	27.9
28........	251.0	−12.8	−13.0	20.9
29........	340.4	−34.9	35.2	30.7
30......	260.4	6.8	6.7	−6.1
31....	168.2	37.5	36.7	37.2
32...	3.0	+37.1	+38.2	45.0

The discrepancy which is exhibited by the velocities obtained in January and February when compared with all the others, as well as the different values of the period which they yield, cannot be explained with certainty at present. However, I should not wish to leave unmentioned a certain possible cause, which is a rapid motion of the line of apsides in the direction of the orbital motion of the star. Such a case is known to be possible when a disturbing force exists, due to a flattening of the central body, and the probability of this explanation is increased by Dunér's analogous investigation of the variable star Y Cygni, the unequal periods of which are explained by the motion of the line of apsides. It is hardly necessary to point out that in this case the available data are hardly sufficient to determine the amount of the motion.

PULKOWA, November 1896.

ON AN AUTOMATIC ARRANGEMENT FOR GIVING BREADTH TO STELLAR SPECTRA ON A PHOTOGRAPHIC PLATE.

By William Huggins.

In my original paper on the "Photographic Spectra of Stars" (*Phil. Trans.*, **171**, Part II, p. 672, 1880) I point out that the necessary breadth may be given to a photographic spectrum, without the use of a cylindrical lens, by simply causing the star's image to travel slowly in the direction of the length of the slit. At present it is usual, the length of the slit being fixed in the direction of the star's motion, by making the rate of the clock slightly fast, to cause the star to travel slowly along the slit, and when it has passed through a distance corresponding to the breadth which is desired for the photographic spectrum, by means of the slow-motion arrangements of the equatorial, to bring the star back to its first position; and in this way, by a sufficient number of runs of a fixed length, to make up the time of exposure which may be required. Without the assistance of an efficient electric control on the speed of the clock, this periodical bringing back of the telescope during a long exposure becomes very irksome, and brings in a serious loss of time. Even if the telescope is provided with a modern electric clock control, the method of successive runs by hand is troublesome and fatiguing, with the very long exposure so often necessary.

A few years ago an automatic arrangement suggested itself to me by which any desired amount of breadth could be given to photographic spectra with great precision and without interference by hand, except so far as may be required by change of refraction or from error of the clock rate. In this plan of working the clock must not be fast, but accurately adjusted to the motion of the stars, so that the star's image would remain fixed at any point of the slit at which it was put. Then, by means of an adjustable eccentric cam, introduced between the

clock and the driving screw, the stellar image is made to oscillate backwards and forwards about its mean position to any extent that may be desired. It is necessary to have the means of adjusting the amount of eccentricity to the breadth of spectrum desirable with the spectroscope which is in use; and also the means of removing, at pleasure, the eccentric motion when it is not required.

I took some spectra by this method some years ago, but the wheel which I then employed could not be made sufficiently eccentric. Recently I have had constructed a very simple eccentric arrangement which fulfils these conditions.

The clock-motion on its way to the driving-screw passes through two wheels gearing into each other, of the same diameter and of the same number of teeth. One of the wheels is provided with a cam by which the axis can be moved outside the center of figure of the wheel. This is effected by moving a small lever on the front of the wheel, which can then be fixed by a clamp in a position corresponding to any desired amount of eccentricity, or breadth of spectrum, within the range furnished by the cam. It is only necessary to bring back the lever to its first position, and to screw up the clamp, to make the wheel concentric, when the clock-motion will be transmitted to the driving screw without alteration of rate.

It is obvious that when the wheel is made eccentric, the star will slowly travel to and fro about its mean position. The time required to make a complete revolution in my instrument is about two minutes.

It should be pointed out that as the teeth of the eccentric wheel alternately approach and recede from the other wheel during each revolution, the teeth of both wheels should be long and suitably shaped, so as to allow of considerable interpenetration when the center of figure of the eccentric wheel is on the side of the axis which is nearer to the other wheel.

When such an eccentric wheel is employed the exposure increases towards the ends of the runs, that is, towards the two edges of the spectrum. If the unequal photographic action be

considered an objection, some other mechanical arrangement may be substituted for the eccentric wheel. For instance, a suitable automatic action upon the electric control of the clock, or upon a "mouse wheel." A simpler plan is to have both wheels of the pair concentric, but one of them furnished on one-half of its circumference with one tooth, or at most two teeth more, and on the other half with the same number of teeth fewer than the number required to transmit the clock-motion without alteration. The difference in the number of teeth would be too small to prevent good gearing of the wheels; and in this case the exposure would be uniform throughout the runs, and the photographs uniform throughout the breadth of the spectrum.

By the use of an automatic mechanical arrangement not only will the personal fatigue of the observer be greatly lessened, but, what is of no little importance in a variable climate, the necessary time of exposure will be reduced, for every moment of the exposure will tell upon the plate, since there will come in no interruptions of photographic action, through any want of immediate and accurate bringing back of the star at the end of each run, as can scarcely fail to be the case when it has to be done by hand.

LONDON, November 23, 1896.

PLATE II.

N

E

W

S

Enlarged twice

THE CLUSTER MESSIER 35

R. A. 6 hours 3 minutes; N. D. 24° 20′. Exposure 2 hours 10 minutes; 6-inch portrait lens

Lick Observatory Feb. 1, 1894. E. E. BARNARD

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XVI.

By Henry A. Rowland.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3259.720		0	3265.454	Co	0 N
3259.834		0	3265.678		2
3259.977		0000 N	3265.762	Fe	4
3260.110	Cr, Fe	4	3265.822		00
3260.266		000	3266.016	V	1
3260.386 s	Mn, Ti- Fe	5 d?	3266.102		000
3260.593		0000	3266.275		000
3260.673		00	3266.362		000
3260.813		000 N	3266.561		00 Nt?
3260.950	Co	1	3266.798		3 N
3261.079		0000 N	3267.072		1
3261.186		00 N d?	3267.184		1
3261.319		0000 N	3267.328		00
3261.460	Fe	2	3267.391		000
3261.705	Ti	3	3267.561		00
3261.760		4	3267.661		0000 N
3261.938		00	3267.834 s	V	6
3262.142	Fe	2	3267.910	Mn	0000
3262.409	Fe- Sn	3	3268.186		1
3262.558		0000	3268.366	Fe	3
3262.838		0000 N	3268.468		0000
3263.023		3	3268.558		0000
3263.194		1	3268.644		00
3263.254		0000	3268.847	Mn	0000
3263.355	V, Co	0	3268.983		000
3263.491	Fe	4	3269.098		0
3263.587		0000	3269.207		000
3263.813	Ti	4	3269.355	Fe	1
3263.960		0 N	3269.462	Fe	00
3264.097		0	3269.555		0
3264.187		0	3269.627		0
3264.307		00 N	3269.747	Zr	0000 N
3264.405		1	3269.890		1
3264.528	Mo?	0	3270.033		000
3264.646	Fe	4	3270.089	Fe	2
3264.833	Mn	2	3270.265	-,Co	1 N
3264.906	Co	2	3270.473	Mn	00
3264.983		00	3270.656		0000 N
3265.176	Fe,-	3 d?	3270.794	Ti?	0
3265.310		0000	3270.872		0000 N

Wave-length	Substance	Intensity and Character	Wave length	Substance	Intensity and Character
3271.129	Fe	6	3278.221		000 N
3271.266	Ni, Co, Zr, V	5	3278.420	Ti	5
3271.436		0000	3278.574		0000
3271.536		0000	3278.687	Mn	1
3271.621	Fe	1	3278.867	Fe	3
3271.791	Ti, Fe	6d?	3278.974		00
3271.918	Co	0	3279.060	Ti	4
3272.085		0000 N	3279.279		1
3272.217	Ti	5	3279.400	Zr, Co	2
3272.367	Zr	2	3279.574		0000
3272.558		0000 Nd?	3279.644		0000
3272.729		1	3279.784		0
3272.855		0	3279.872	Fe	1
3272.971		0000 N	3279.973	V	1
3273.175	Mn Zr	2	3280.120	Ti	2
3273.311		0000	3280.256		000 N
3273.477		000	3280.302	Fe	4
3273.606		1 N	3280.493		0000 N
3273.758		0	3280.623		0000 N
3273.844		0000	3280.806	Ag	0
3273.970		0000 N	3280.900	Mn	1
3274.096 s	Cu	10	3281.100		0000Nd?
3274.350		1	3281.250		0 N
3274.575	Fe	3	3281.429	Fe	5
3274.677		0000	3281.652		0000
3274.800		0	3281.725		0000
3274.907		0000	3281.841		2
3275.033		1	3281.993	Ni	2 d?
3275.149		0000	3282.122		000
3275.276		0000	3282.372		00
3275.353		0000	3282.459	Ti, Zn	5
3275.423	Ti	3	3282.572		0
3275.529		0000	3282.665	V	1
3275.603		0000	3282.830	Ni	2
3275.716		000	3282.962	Ni	2
3275.809		1	3283.029	Fe	2
3275.969		0 N	3283.179		000
3276.103		000	3283.286		00
3276.259	V	5 d?	3283.332		00
3276.386		00	3283.458	Co	0
3276.594	Co, Fe	3	3283.576	Co,-	2
3276.741		1	3283.686	Fe	1
3276.905	Ti	3	3283.812		0000
3277.124	Ti	2	3283.929		00 N
3277.225		0000	3284.059		00
3277.315		0	3284.116		00
3277.482	Co Fe	7 d?	3284.256		0000 N
3277.795	Co	0 N	3284.366		0000
3277.848		0 N	3284.486		0000
3277.997		0 N	3284.550	Ni	1

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3284.648		0	3290.375		00
3284.723	Fe	2	3290.475		0000
3284.847	Zr	1	3290.602		00
3284.968		0000	3290.642		0 N
3285.148		0 N	3290.765		000
3285.324		1	3290.842	Fe	2
3285.421		0	3291.119	Fe	4
3285.547	Fe	2	3291.261		0 N
3285.678		00	3291.411		0900
3285.828		0000	3291.557		00
3285.908		0000	3291.671		000
3286.034	Fe?, Ti?	000 N	3291.824	Fe	00
3286.164		2	3291.897		1
3286.197		0	3292.151 } S	Fe	4
3286.310		0000	3292.206 } S	Ti, Co	3
3286.384		000	3292.337		0000 N
3286.494		0000	3292.451		0
3286.580		1	3292.636		0
3286.667		00	3292.728	Fe	4
3286.784		0	3292.870		0000 N
3286.898	Fe	7 N	3292.996	Mn?	000
3286.980		0 N	3293.053		00
3287.086	Ni	3	3293.276	Fe, Co	2
3287.224	Fe	2	3293.350		0000
3287.347	Co	2	3293.605		00
3287.460	Zr?	000	3293.800	Fe	1
3287.560		000	3293.900		00
3287.597		000	3293.989	Co?	000 N
3287.709		0000	3294.125		0000 N
3287.793 S	Ti	5	3294.235		0000 N
3287.863		0000	3294.325		000 N
3287.986		0000 N	3294.462		0000 N
3288.175		0	3294.569		0000 N
3288.281	Ti	3	3294.682		0000
3288.453	Fe	00 N	3294.749	Co	00
3288.561	Ti	2	3294.849		000
3288.705	Ti	2	3294.949		00 N
3288.801	Fe	1	3295.069	Ti	0
3288.939	Zr	0	3295.149		0000
3289.103	Fe	2	3295.243		0
3289.153		0	3295.375		1
3289.272		0000	3295.562		2
3289.372		0000	3295.732		000
3289.498		4	3295.762		0000
3289.568	V	3	3295.951 S	Fe, Mn	6
3289.705		0000 N	3296.168	Mn?	00
3289.875		0000	3296.388		1 N
3289.988		000	3296.504	Zr?	000 N
3290.035		000	3296.602	Fe	2
3290.238		0000 N	3296.721		0000 N

Wave length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3296.948		1	3302.895		0000
3297.014	Mn	1	3302.990		3
3297.194		0 N	3303.109 S	Na	5
3297.301	Co	0	3303.248	La	000 Nd?
3297.381		0	[1]3303.398	Mn	00 N
3297.511		000	[1]3303.601 } S		3
3297.644		000	3303.698 }	Fe	2
3297.720		000	3303.908		000
3297.793		000	3304.022		0000 N
3297.963		0 N	3304.263		000
3298.009		1	3304.375	Mo?	1
3298.140		0000	3304.492		0
3298.268	Fe, V, Di	5	3304.577		000
3298.361	Mn	000	3304.611		000
3298.451		0000	3304.719		00
3298.545		0000	3304.881		00 N
3298.685		1	3305.001	Mn	00
3298.818	Co	2	3305.089	Ni	1
3298.869	V	3	3305.194		000
3298.995		0000	3305.283	Co-Zr	2
3299.211		1	3305.354		000
3299.305		0000	3305.434		0000
3299.477		0000	3305.541		0000
3299.564	Ti	2	3305.604		0000
3299.652	Mn	0 Nd?	3305.754		000 N
3299.804		0	3305.877	Co	0
3299.905		0	3305.991		2
3300.017		000	3306.105 S	Fe	4 N
3300.204		0000 N	3306.221		2 N
3300.297		00 N	3306.296		0000
3300.444		0000 Nd?	3306.412 } S	Zr	2
3300.617		000	3306.506 }	Fe	4
3300.687		0000 N	3306.623	Co	1
3300.802		000	3306.726		1
3300.944		0000	3306.830		000
3301.039		000	3306.903		0000
3301.143		0000 N	3307.010	Ti	00
3301.263		0000 N	3307.114	Mn	1
3301.352	Fe	1	3307.165	Fe	2
3301.552	Fe	0	3307.280	Co	1
3301.706		0000	3307.374	Fe	1
3301.808	Ti, Sr	1	3307.473		0000
3301.909		0000	3307.650	Sr?	000 N
3301.996		0000	3307.845	Fe	4
3302.055	Fe	0	3308.035		00 N
3302.232	Ti, Pd	4	3308.239		0 N
3302.289		0000 N	3308.405		0000
3302.443		0000 N	3308.527	Ti	0
3302.510 S	Na	6	3308.619	Co	00
3302.720	Zn	1	3308.749		000

[1] A zinc line comes between these two.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3308.888 } S	Mn	2	3314.476		000 N
3308.947 } S		5	3314.574	Ti, Fe, Mn	3 N
3309.065	Co, Ti	0000 N	3314.663	Ti	2
3309.159		0000	3314.742		000 N
3309.212		0000	3314.876	Fe	4
3309.325		0000 N	3314.995	Mn	0
3309.452		0000 N	3315.178	Co	000 N
3309.558	Ni	0	3315.303		0
3309.658	Ti,-	2 N	3315.385		0000
3309.851	Ti	00 N	3315.457	Ti	3
3309.974		0000	3315.548		0
3310.031		0000	3315.685		0000 N
3310.158		000	3315.807	Ni	7 d?
3310.248		0000	3316.081		0000
3310.338	Ni	2	3316.128		0000
3310.472	Fe	3	3316.325		000 Nd?
3310.626	Fe	2	3316.467		00
3310.777		1 N	3316.561	Mn	0
3310.996		0	3316.615		0000
3311.041		000	3316.698	Mn	00
3311.051		0000	3316.778		00
3311.238		0	3316.871		00
3311.343		00	3316.980		0
3311.477		000	3317.034		0000
3311.587		00	3317.174		00
3311.727		0000	3317.262	Fe	2
3311.843		000	3317.393	Mn	1
3312.023		0	3317.514		0
3312.063	Mn	2	3317.720		0
3312.187		0000	3317.830		0000
3312.325	Fe-Co	3 d?	3317.960		0000
3312.453	Co	2	3318.160 S	Ti	6
3312.563		00	3318.339		000
3312.729		1	3318.496	Ti-Co	1 Nd?
3312.827	Ti, Fe	2	3318.645	Zr	00
3312.970	Co	000	3318.741		000 N
3313.053		000	3318.895		00
3313.137	Ni	1	3319.035		0000Nd?
3313.206	Co	000	3319.172	Zr	0
3313.301	Mn	00	3319.207		1
3313.432		0000 N	3319.298	Co	00
3313.562	Mn	00	3319.387	Fe	2
3313.676		000 N	3319.491		000
3313.774		1	3319.619	Co	1
3313.853		0	3319.673		0
3313.929		0000	3319.815		0000
3314.042		00 N	3319.953	Co	0
3314.124		1	3320.032		0
3314.214	Co	1	3320.161		0000
3314.334	Mn	0	3320.258		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3320.391	Ni	7	3326.335		00
3320.508		0000	3326.432		000
3320.621		0000	3326.553		0
3320.783	Mn, Fe	2	3326.727		0 N
3320.907	Fe, Ni	1	3326.825	Co	1
3321.044		0000	3326.907[1]	Ti	5
3321.177	Be?	0000 N	3326.998[1]		3
3321.324		000	3327.127	Co	1
3321.366		0	3327.297		00
3321.494		0000	3327.424		0000
3321.550	Be?	000	3327.533	Ni	2
3321.667		00	3327.633	Fe	1
3321.715	Ti	00	3327.757		000
3321.836	Ti, -	4	3327.861		0000 N
3322.047		000 N	3328.016	Di?	2
3322.190		0000	3328.101		0
3322.331	Co	1 Nd?	3328.341	Co	00
3322.454	Ni	3	3328.487		2
3322.610	Fe	2	3328.605		0
3322.784		00	3328.713		0000
3322.833		00	3328.849	Ni	1
3323.003		1	3328.933		0000
3323.056[1]	Ti	5	3329.000	Fe	3
3323.116[1]		3	3329.186	Cr, Fe	1
3323.213		1	3329.233		000
3323.256		00	3329.338		0000
3323.426		0000	3329.435		0000 N
3323.524		1	3329.568[1]	Ti, Co	5
3323.669		0	3329.648[1]		3
3323.881	Fe	3	3329.762	Fe	0000 N
3324.049		000	3329.902		\ 00
3324.129		0	3329.982		/ 000
3324.201		4 N	3330.044	Mg	3
3324.280		0	3330.102		2
3324.494	Fe	1	3330.212	Sr?	000
3324.674	Fe	3	3330.364		0
3324.808		0	3330.438		1
3324.921		1	3330.565		0000 N
3325.142		0	3330.645		000
3325.168		0000	3330.745	Sn?	000
3325.288		0000	3330.802	Mn	00
3325.381	Co	1	3330.914		000
3325.462		000	3331.056		1 N
3325.609	Fe	3	3331.194		000 N
3325.712		000	3331.384		00 N
3325.820		0000	3331.527		000
3325.886		0000	3331.747 s	Fe	2
3326.028		000	3331.915	Fe	2
3326.105		0000	3332.061		000 N
3326.212		0000	3332.184		0

[1] See note to 3335.[illegible], 3335.350, etc.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3332.240	Ti	3	3338.054[1]		0
3332.326	Mg	3	3338.141		0000
3332.421		000 N	3338.247		0
3332.481		00	3338.368		000
3332.707		0000 N	3338.478		000
3332.850		0000	3338.561		000
3332.965		0	3338.651	Co	00
3333.026		0000	3338.759	Fe	2
3333.160		000	3338.905		0
3333.250		0	3338.944		0000
3333.353		000 N	3339.051		0000 N
3333.526	Co	2	3339.180	Ni?	1
3333.728		1	3339.333	Fe	2
3333.854		0	3339.438		000 N
3333.953		000	3339.577		000 N
3334.046		000	3339.713	Fe	1
3334.116		000	3339.818		1
3334.266	Co	4	3339.932	Co, Cr	3
3334.356	Fe	1	3240.011		1
3334.406	Zr?	1	3340.173		000 N
3334.613		0	3340.310		0000 N
3334.753	Zr	0	3340.464[1]	Ti	3
3334.846		0	3340.523[1]		2
3334.933		0000 N	3340.702	Fe	2
3335.065		000 N	3340.823		00 N
3335.192		0000 N	3340.957		0000 N
3335.299[1]	Ti	4	3341.027		1
3335.350[1]		2	3341.137		0000
3335.439		1	3341.300		0000 N
3335.553		1 N	3341.417		0000
3335.666		2 N d?	3341.480	Co	00
3335.859		1	3341.583		0000
3335.915	Fe	2	3341.690		0000
3335.979		000	3341.820		000
3336.054		0	3341.967[1]	Ti	4
3336.259		0	3342.062[1]	Fe,-	4
3336.391	Fe	2	3342.280		0
3336.477	Cr	2	3342.358	Fe, Ti	3
3336.635		00 N	3342.442	Fe	3
3336.679		00	3342.506		0000
3336.820	Mg	8 N	3342.606		0000
3336.962		0 N	3342.717	Cr	3
3337.098		0	3342.829	Ti	00
3337.138		1	3342.892	Co	00
3337.319	Co	1 N	3343.032		00
3337.471		0000	3343.156		00
3337.524		000	3343.366		0
3337.630	La	0	3343.479		00
3337.803	Fe	3	3343.656		000 N
3337.984[1]	Ti	2	3343.804	Mn	1

[1] There are several cases like this where there is a close double, one line at least belonging to Ti. It is not certain in such cases that both are not Ti lines. Possibly the second may be Ti and not the first. The notes do not yet settle these cases, except 3314.573 and 3314.663, when both lines belong to Ti.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3343.908	Ti	4	3349.965		0000
3344.036		0000 N	3350.080		000 N
3344.215		000 N	3350.214		000 N
3344.315		00	3350.347		2
3344.521		0000 N	3350.429		1
3344.655	La	2	3350.512		1
3344.721		0000	3350.545	Di?	1
3344.831		0000 N	3350.648	Ti	2
3344.924	Zr	0	3350.985		000
3345.015		000	3351.089		000
3345.068		2	3351.201		00
3345.156	Zn	2	3351.289		0000
3345.298		0000 N	3351.379		0000
3345.495	Mn	00	3351.472		0000
3345.618		000	3351.551		0000
3345.715	Zn-	1	3351.658	Co-Fe	2
3345.761		00	3351.745	Cr	0
3345.835		00	3351.884 s	Fe	1
3345.955		000 N	3352.101	Cr	0
3346.047		000 N	3352.198	Ti	2
3346.154	Cr, Zn	0 N	3352.318		0000 N
3346.284		00	3352.578		000 N
3346.414		00	3352.771		00 N
3346.557		0	3352.908		000
3346.734		0000 N	3352.958		000
3346.860 [1]	Cr	3	3353.065	Ti, Fe	1
3346.904 [1]	Ti	2	3353.262		2
3347.066	Co	2	3353.402	Fe	1
3347.157		0000	3353.538		000 N
3347.267		0000 N	3353.661		0000 N
3347.450		000	3353.708	Zr	00 N
3347.507		000	3353.875		4
3347.638		0	3354.057		000 N
3347.760		00 N	3354.199	Fe	2
3347.970	Cr	3	3354.350	Co	00 N
3348.072	Fe	3	3354.523	Co, Zr	3
3348.254	Co	1	3354.670		00
3348.370		0000 N	3354.778	Ti	3
3348.520		0000 N	3355.023		00 N
3348.673		000	3355.197		0000 N
3348.820		000	3355.363	Fe	4
3349.043	Ti	4	3355.497		0000 N
3349.135	Ti, Cr	3	3355.661	Mn	0
3349.212	Ti	2	3355.797		0000 N
3349.399		00	3355.957		000 N
3349.519	Cr	2	3356.080		000
3349.597	Ti	7	3356.231 s	Zr	1
3349.695		00	3356.370		000 Nd?
3349.785		00	3356.462		2
3349.874		0	3356.548	Fe	2

[1] See note to 3335.200, etc.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3356.676	Co	000 N	3362.402		2 d?
3356.821	Fe	2	3362.528		0
3356.976		000	3362.727		0000
3357.092		0000	3362.782		1
3357.256		000 N	3362.936	Co	4 Nd?
3357.412	Zr	2	3363.107		0
3357.537		1	3363.298		0000 N
3357.703		0	3363.442	Co	0 d?
3357.816		0000	3363.542		1
3357.874		0	3363.750	Ni	1
3357.959		00	3363.854		1
3358.076		0000	3363.955	Co	0
3358.182		1 N	3364.055		0
3358.276		0000	3364.148		00
3358.416	Ti	3	3364.232		0000
3358.542		00	3364.362		00
3358.649	Ti-Cr	4	3364.408	Co	1
3358.771		00	3364.535		0 Nd?
3358.832		0	3364.749	Ni,-	3 d?
3358.929		00	3364.832		00
3359.035		2 N	3365.081		0000
3359.144		00	3365.167		0000
3359.248	Ni	3 N	3365.247		0000
3359.420	Co	1	3365.341		00
3359.542		1	3365.451		0000 N
3359.636	Fe?	2	3365.581		0
3359.769		1	3365.684		00
3359.823		2	3365.908	Ni	6
3359.936		1 N	3366.127		000
3360.066		0	3366.311	Ti, Ni	6 d?
3360.181		2	3366.494		000
3360.258		0	3366.594		000
3360.345		0	3366.687		0000
3360.444	Ni	2	3366.791		0000 N
3360.485	Cr	1	3366.931	Ni, Fe	3
3360.631		0	3367 009	Fe	3
3360.741		0	3367.117		000
3360.828		0	3367.233	Co	2
3360.988		0	3367.297	Fe?	1
3361.055	Ti	1	3367.434		00
3361.141		0	3367.527		0000
3361.241		1	3367.575		0
3361.327	Ti	8	3367.687		0
3361.421		2	3367.812		0
3361.568		0 N	3367.953		000
3361.704	Co,-	3 Nd?	3368.029	Ti, Ni, Fe	2
3361.906		1	3368.193	Cr,-	5 d?
3361.988		0	3368.319	Mn	1
3362.087	Ti	2	3368.382		000
3362.275		1	3368.496		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3368.580		0000	3374.271		000
3368.680		00	3374.358	Ni	4
3368.793		00	3374.487	Ti, Co	2
3368.860		00	3374.588	Fe	1
3368.956		0	3374.778	Ni	2
3369.083		3 d?	3374.872	Zr	1
3369.190		0	3374.981		000
3369.286		0	3375.068		0
3369.352	Ti, Mn	1	3375.231		00
3369.506		0 N	3375.351		0000
3369.633		0	3375.478		0 N
3369.713	Fe, Ni	6	3375.601		0000
3369.800		1	3375.698	Ni	1
3369.932		0	3375.768		000
3370.052		0	3375.860		0
3370.173		00	3375.991		0000
3370.330		0 N	3376.081		0000
3370.468	Co	2	3376.164		00
3370.584	Ti	2	3376.238		000
3370.770	Zr, Mn	1 Nd?	3376.341		0000
3370.933	Fe	4	3376.414		0
3371.020		000	3376.471	La	2
3371.110		0	3376.630	Fe	2
3371.246		00	3376.731		0000
3371.296		00	3376.814		0000
3371.431		0	3376.894		000
3371.535		00	3376.978		000
3371.593	Ti	3	3377.084		0000
3371.745		000	3377.202	Co	0 N
3371.852		00	3377.408		00
3371.899		00	3377.497		0000
3372.124	Ni,-	4	3377.622 } S	Ti	3
3372.225	Fe	1	3377.723 }	Ti	3
3372.314		0	3377.837		0000 N
3372.362	Ti	2	3377.943		0000 N
3372.488	Fe	0	3378.114		1
3372.609	Fe	00 N	3378.203		000
3372.759		0 N	3378.320		00
3372.901	Ti-Pd	{ 5	3378.476	Cr, Co?	2
3372.994		} 5	3378.723		00
3373.105		0 N	3378.824	Fe	2
3373.229		000	3378.881	Co	1
3373.369	Co	0	3379.005	Mn	0 N
3373.452		0	3379.161	Fe	2
3373.555	Zr	0	3379.337	Ti, Cr	2 d?
3373.642		0	3379.514	Cr	2
3373.742		0000	3379.577		000
3373.872		0000	3379.687		0000
3374.016	Fe	1	3379.783		0000
3374.110		2	3379.843		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3379.961	Cr	3	3385.577	Fe	1
3380.060	Zr, Ti	1	3385.688	Fe	1
3380.157		0000	3385.809	Ti	1
3380.255	Fe	3	3385.861	Fe?	00
3380.397 [1]	Ti	3	3386.005		0000 N
3380.450 [1]		3	3386.085	Ti, Mn	3
3380.605		0	3386.310		00 N
3380.722	Ni	6 N	3386.408		000
3380.889	Sr?	1	3386.488		000
3381.026	Ni, La	5 Nd?	3386.588		000
3381.202		0000	3386.691		00 N
3381.269		1	3386.875		000
3381.490	Fe	2	3386.921		000
3381.632		000	3387.014		000
3381.669		000	3387.194		000 N
3381.786		0000	3387.307		000
3381.896		000	3387.444		0
3382.002		000	3387.554	Fe	2
3382.129	Mn	0	3387.600		0
3382.224		00 N	3387.762	Fe	1
3382.340		0	3387.854		00
3382.450	Ti	1	3387.988	Ti-Zr	5 d?
3382.549	Fe	2	3388.190		0000
3382.604	Di?	1	3388.311	Co	3
3382.724		000	3388.473	Zr	1
3382.825	Cr, Mn	4	3388.604		0 N
3382.926		0000	3388.761	La?	1
3383.036		00	3388.896	Ti	2
3383.129		0	3388.994		00
3383.232		0000 N	3389.107		1
3383.342		0000 N	3389.257		000
3383.449	Ag	000	3389.387		00
3383.512		0	3389.460		00
3383.629		000 N	3389.540		0
3383.709		0	3389.747		0000 N
3383.833	Fe	3	3389.884 s	Fe	2
3383.951	Ti	3	3389.960		0000
3384.133	Fe	3	3390.060		0000
3384.225		00	3390.154		000
3384.375		000	3390.244		000 Nd?
3384.461		000	3390.400		00
3384.561		000	3390.544		00
3384.728		0000 N	3390.654		000
3384.782		00	3390.736		000
3384.908		1	3390.819	Ti	0
3385.061		0000	3390.919		00
3385.167		0	3391.033		00 N
3385.215		000	3391.175	Ni	5
3385.361	Co	3	3391.243		1 N
3385.468		0000	3391.409		0000 N

[1] See note to 3335.299, etc.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3391.509		0000 N	3397.451		0000
3391.578	Cr	2	3397.571		00
3391.726		0	3397.691	V?	1
3391.806		0000 N	3397.779	Fe	2
3391.977		0	3397.931		00
3392.109	Zr	2	3397.974		000
3392.153	Fe	1	3398.151		0000 N
3392.259		0	3398.244		0000 N
3392.441	Fe	3	3398.357	Fe	1
3392.633		00 N	3398.441		00
3392.759	Fe	2	3398.511		0
3392.813		1	3398.551		0000 N
3392.926	Ti	0	3398.746	Ti	00 N
3393.029		0	3398.839		000
3393.113	Ni	3	3398.949		000
3393.160	Cr	1	3399.059		0
3393.285	Zr	1	3399.126		0000
3393.427		0	3399.204		00
3393.526	Fe	1	3399.376	Fe, Zr	2
3393.845		1 Nd?	3399.489	Fe	3
3393.980	Cr	2	3399.654		0
3394.062	Fe	1	3399.746		0000
3394.220	Fe	1	3399.942		0 N
3394.432	Cr	2	3400.153		0000 N
3394.518	Fe	0	3400.279		000
3394.685	Ti	3	3400.366		0000
3394.746	Fe	3	3400.529		000
3394.875		0000	3400.629		0000
3394.958		0000	3400.779		1
3395.085		0000 N	3400.979		0000
3395.212		0	3401.121		1
3395.408		00 N	3401.307	Ni	1
3395.505	Co	{ 3	3401.478		000
3395.544		{ 2	3401.664	Fe	3
3395.750		0	3401.778		0000 N
3395.882		0	3401.900		0
3396.012		000	3401.992		000
3396.125		0	3402.058		000
3396.178		0	3402.208		000
3396.320	Ni	1	3402.262		000
3396.437		0	3402.352		000
3396.523		0	3402.400	Fe	3
3396.642		000	3402.553	Ti	3
3396.742		0000	3402.685		0
3396.792		00	3402.842		0000
3396.965		0000	3402.925		000
3397.062		0000	3403.033		0
3397.116	Fe	3	3403.145		0000 N
3397.197		0000	3403.288		0000 N
3397.356		1	3403.494	Cr	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3403.478	Fe, Ti	2	3409.346	Fe	2
3403.572	Ni	2	3409.530		000 N
3403.725		000 N	3409.711	Ni	2
3403.826		0	3409.803		0
3403.925		0000	3409.950	Ti	2
3404.005		0000	3410.080		00
3404.128		0000	3410.170		1
3404.202		000 N	3410.313	Fe	2
3404.292		0000	3410.386	Zr	1
3404.413	Fe	2	3410.526		0000 N
3404.511	Fe	3	3410.696		00
3404.581		0000 N	3410.783		0000 N
3404.717	Pd	0	3410.923		00
3404.897		1	3411.035	Fe	2
3404.972	Zr	0	3411.160		00 Nd?
3405.044	C?	0	3411.274	Fe	1
3405.097		00	3411.366		0000
3405.217 } s	Co	2	3411.498	Fe	3
3405.302 }		2	3411.700		0000
3405.504		000	3411.883		000
3405.637		0000	3412.009		000
3405.716	Fe	0	3412.109		000
3405.837		0000 N	3412.162		0000
3405.971	Fe	1	3412.302		0000 N
3406.111		000 N	3412.481	Co	5
3406.254		00	3412.595		0000
3406.304		00	3412.775	Co	4
3406.391		0000	3412.909		0000 N
3406.491		0000	3413.019		000
3406.572 s	Fe	3	3413.275	Fe	5 d?
3406.697		0	3413.402		000 N
3406.943 s	Fe	5 d?	3413.542		00
3407.187		000	3413.597	Ni	2
3407.338	Ti	2	3413.651		2
3407.447		2	3413.782		0
3407.537		00	3413.855		00
3407.597	Fe	4	3413.935		0000
3407.693		3	3414.079	Ni	4
3407.844		0000 N	3414.269		00 N
3407.937	Di?	0	3414.399		000 N
3408.091		00 Nd?	3414.535		000 N
3408.217		0	3414.643		1
3408.317		0000 N	3414.769		1
3408.484		0000 N	3414.911	Ni	15
3408.637		000 Nd?	3415.050		1 Nd?
3408.811		000 N	3415.230		0
3408.911	Cr	3	3415.279		00
3409.070		1	3415.462		0000 N
3409.210		0000	3415.575		0000
3409.302	Co	2	3415.672	Fe	3

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3415.815		0	3422.033		0000
3415.922		00 N	3422.087		0000
3416.029		0000	3422.260		1
3416.164		3	3422.347		0000
3416.274		0000	3422.468	Ni	1
3416.421		1	3422.629	Fe	4
3416.541		0000	3422.794	Fe	3
3416.644		000 N	3422.892	Cr	4
3416.771		00	3423.016	Ni	1
3416.808		0	3423.153		0000 N
3416.914		00	3423.307		000 N
3417.001		00	3423.380		00 N
3417.095	Ti	1	3423.453		000 N
3417.198		00	3423.667		00 N
3417.301	Co	3	3423.760		0 N
3417.401	Fe	1	3423.848	Ni	7
3417.491		000	3423.972		0 N
3417.618		0000	3424.127		0
3417.681		0000	3424.311		00
3417.819	Co	00	3424.432	Fe	4
3417.948	Fe	2	3424.579		0000 N
3418.002		2	3424.646	Co	0
3418.161		0000	3424.732		000
3418.303	Fe	1	3424.846		000
3418.448		0000 N	3424.966	Zr	00
3418.654	Fe	5	3425.152	Fe	4
3418.864		000 N	3425.196		000
3419.013		1	3425.432		0000 N
3419.108		0000 N	3425.579		0000 N
3419.282	Fe	1	3425.716 s		2
3419.424		000 N	3425.879		0000 N
3419.554		000 N	3425.976		00
3419.836	Fe	2	3426.102		000
3420.013		000	3426.226		000
3420.133		000	3426.349		0000
3420.240		00	3426.466	Fe	3
3420.360		000	3426.535	Fe	3
3420.417		00	3426.700	Fe	3
3420.575		0	3426.807		2
3420.620		00	3426.929		0000
3420.730		000	3427.046		0000
3420.880	Ni?	2	3427.126	Fe?	2
3420.940	Mn	00	3427.263 s	Fe	3
3421.147		000	3427.340		1
3421.253		0000 N	3427.492		0000
3421.353	Ni, Cr, Pd	4	3427.596		0000
3421.482	Ni	2	3427.656		00
3421.620		0000 N	3427.746		0000 N
3421.758	Co	0	3427.899		000 N
3421.860		0	3427.972		000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3428.082		0000 N	3434.117		0000
3428.154		0	3434.183		0
3428.341	Fe, Co	4	3434.259		0
3428.459		0000	3434.383		0000
3428.561		1	3434.512		000
3428.626		1	3434.626		0000
3428.776		000	3434.746		0000
3428.892	Co	2	3434.829		0000
3429.066		000	3434.962		000
3429.172		0000	3435.032		000
3429.282		0000 N	3435.102		00
3429.468		00	3435.179		0000 N
3429.605		0000	3435.296		000 N
3429.718		0000 N	3435.382		000 N
3429.851		00	3435.509		0000 N
3429.951		000	3435.628		1
3430.071		0000 Nd?	3435.729		00
3430.218		0000 N	3435.819	Cr	0
3430.295		000	3435.962	Cr	0 N
3430.428		00	3436.174		1
3430.545		00 N	3436.250		0
3430.671	Zr	1	3436.332	Cr	2
3430.777		0000 N	3436.472		0000 N
3430.870		0000 N	3436.552		000 N
3431.020		000	3436.666		0000 N
3431.090		000	3436.786		0000
3431.207		0000	3436.882		000
3431.320		0000	3436.976		0000 N
3431.423		00	3437.116		000 N
3431.590		0000 N	3437.190	Fe	3
3431.721	Co	4	3437.282	Zr	00
3431.830		000	3437.427	Ni	5 d?
3431.965	Fe	3	3437.616		0000Nd?
3432.077		000	3437.772		00
3432.157		0	3437.829		00
3432.270		000	3437.926		0000
3432.350		0000	3438.012		0000
3432.447	Co	0	3438.094	Fe	2
3432.550		00	3438.236		000
3432.707		0000	3438.376	Zr	2
3432.863		0	3438.455	Fe	1
3433.023		000	3438.556		0000 N
3433.163	Co	3	3438.639		000 N
3433.212	Cr, C?	2	3438.851		000 N
3433.290	Pd	0000	3439.092	Mn?	2
3433.453	Cr	3	3439.171	Fe	2
3433.591		0	3439.268		0000 N
3433.715	Ni, Cr	8 d?	3439.365		000 N
3433.905		0 N	3439.478		00 Nd?
3434.053		0000	3439.635		000 N

ON THE APPLICATION OF INTERFERENCE METHODS TO THE DETERMINATION OF THE EFFECTIVE WAVE-LENGTH OF STARLIGHT.

By George C. Comstock.

The experiments to be set forth in the present paper grew out of and are collateral to an investigation of the atmospheric refraction contained in *Publications of the Washburn Observatory*, Vol. IX. The discussion of those observations, pp. 185–190, seemed to show a sensible difference in the amount of the refraction, depending upon the color of the star in question, a difference which might indeed be expected *a priori* since, the color being produced by selective absorption in the stellar atmosphere, it may be assumed that the average wave-length and the corresponding refraction of the light received from a red star will be in some measure different from that of a star in whose spectrum the violet and blue rays have not suffered an absorption relatively so great.

But since the colors thus produced cannot, in general, be saturated and will usually be quite different from the pure spectral colors, the average wave-length of the light of a given star must not be assumed to be even approximately determined by matching its color, as nearly as may be, with that of a definite part of the solar spectrum, and the same holds true, *a fortiori* for the effective wave-length if we understand by that term the wave-length of that part of the stellar spectrum which the observer adopts as determining the position of the star and upon which his attention is concentrated in the observing. It does indeed result, at least apparently, from the investigation above cited that the wave-lengths determined for the stellar colors there encountered are approximately those of corresponding colors in the solar spectrum and, erroneously as I now think, I have regarded this agreement as a confirmation of the reality of the color effect there investigated.

Recognizing that no very considerable weight can attach to a determination of the color effect made as was the above, I have endeavored to supplement and control it by an entirely independent method, which should give immediately a determination of the effective wave-length of the light of a given star. The term effective wave-length as above defined is nearly equivalent to the wave-length of the (visually) brightest part of the star's spectrum, it being assumed that in ordinary visual observations the observer's attention is concentrated upon this part of the spectrum into which the atmosphere transforms the stellar image.

This assumption is perhaps open to question in the case of very bright stars, but these may be reduced to the case above considered by the use of screens or other appropriate device for diminishing their brightness, recourse to which is frequently had upon quite other grounds.

The value of such determinations of effective wave-length for the more refined investigations of the astronomy of position is apparent and is frequently noted in connection with the determination of the solar parallax from observations of the planets, but little attention has hitherto been paid to a quantitative determination of the color effect. In the literature of the subject accessible to me I have been able to find only one attempt at a determination of effective wave-lengths which can be designated as in any degree successful (Schwarzschild, *A. N.*, No. 3335), and that is limited to a consideration of the mean result furnished by a large number of stars taken without regard to individual differences. The investigations of von Konkoly (*Observatory*, 4, 11) upon the relation of color to wave-length are directed to a different end and his numerical results, which are based upon a comparison of the saturated colors of a Geissler tube with the dilute colors of five stars, give no clue to their effective wave-lengths, as the term is here employed.

As a means of dealing with the problem of differences in effective wave-length I have had recourse to methods based upon the interference of light produced by placing between the star

and the observing telescope (the 40^{cm} Clark equatorial of the Washburn Observatory) an opaque screen in which are cut two narrow rectangular apertures of equal dimensions and with their homologous sides parallel. When light from a bright star is transmitted through these apertures there is produced in the focal plane of the objective a central image of the star and upon opposite sides of this a series of fringes of rapidly diminishing brightness which soon merge into each other and, in the case of very bright stars, become a faint and narrow brush of light streaming away from the central image parallel to the line joining the centers of the apertures. For stars of moderate brightness, third to sixth magnitude, a certain number of the fringes are indistinguishable in appearance from faint stars and the central portion of the interference pattern resembles a multiple star of symmetrical arrangement, the relative position of whose several parts may be determined with a micrometer with all the precision of similar double star observations. The theory of these fringes is contained in the text books of optics, and reference may also be made to a peculiarly succinct and elegant treatment of the subject by M. Hamy (*Bull. Astron.*, **10**, 489).

In general the intensity of the light at any point of the interference pattern is represented by a definite integral whose limits are so determined as to include the entire angular extent of the source of light, but in the case of a fixed star this area may be replaced by a single element of the integral, from which all of the light is supposed to proceed, and if we put (see the article of M. Hamy above cited)

a = the linear width of each slit in the screen.

na = the distance between the axes of the slits.

λ = the wave-length of the light in question.

C = a constant.

θ = the angular distance from the central image of any point on the axis of the interference pattern

we shall have for the intensity of the illumination at any point on the axis of the pattern by a little transformation of M. Hamy's equations

$$I = \left[C \frac{\sin \alpha}{\alpha} \cos n\alpha \right]^2,$$

where α is an auxiliary quantity defined by the relation

$$\alpha = \pi \frac{a}{\lambda} \theta .$$

In the case of an ordinary star whose light is not monochromatic the total brightness must be found by multiplying this value of I by $d\alpha$ and integrating between limits corresponding to the extreme values of λ in the visible spectrum. This process is, however, quite unnecessary for those parts of the pattern in which the fringes are indistinguishable in appearance from faint stars, *e. g.*, of the tenth magnitude, since the total amount of light here present is so small that only the brightest part of the spectrum is visible, and the limits of integration are brought so close together that the single element of the integral, I, may be taken as proportional to the brightness and as determining, through α and θ, the value of λ corresponding to the point of maximum brightness in the spectrum, *i. e.*, the effective wave-length, as shown below.

It is evident that I is a periodic function of α and the points of maximum illumination may be found by differentiating the function with respect to α. We thus obtain as the criterion for the positions of the fringes the transcendental equation

$$\alpha \left[1 - n \tan \alpha \tan n\alpha \right] = \tan \alpha ,$$

which may be solved by trial when n is given. For the apparatus which I have employed

$$n = 2, \qquad a = 27^{\mathrm{mm}}.0, \qquad h = 373^{\mathrm{mm}}.5,$$

where h represents the length of the slits. The first few values of α corresponding to $n = 2$ are

α_0	α_1	α_3	α_5	α_7
$\pm 0^\circ.0$	$\pm 82^\circ.2$	$\pm 265^\circ.9$	$\pm 447^\circ.5$	$\pm 628^\circ.3$

It will be noted that, with exception of the first number, these values are approximately the odd multiples of $\frac{\pi}{2}$ and the distinguishing subscripts are assigned with reference to this relation.

Since α is a function of the wave-length of light, it appears

that the maximum illumination must occur at different points for different values of λ, and the fringes therefore be iris bordered, but this appearance is perceptible to the eye only in the case of the central fringes of a very bright star, since the divisor a^2 which appears in the expression for I corresponds to so rapid a diminution of the brilliancy of successive fringes that only those rays which most strongly excite the retina are visible, the outer fringes being reduced to minute stellar points whose distance from the central image, θ, or from each other, 2θ, may be measured with the micrometer and employed for a determination of the corresponding effective wave-length from the equation

$$\lambda = \pi a \left(\frac{\theta}{a}\right)_i,$$

where i denotes the order of the fringe.

In the determination of wave-lengths, I have uniformly measured the distance, 2θ, between corresponding fringes on opposite sides of the central image, using the most remote fringes which could be seen with sufficient precision to permit of accurate settings of the micrometer threads.

I have observed the common precautions which the experience of double star observers has indicated as essential to the accurate measurement of distances, and in order to bring into the most favorable position the objects whose distance was to be measured, the screen was always placed in front of the objective with the axis of the slits parallel to the declination axis of the telescope.

In order that the observations should extend over a considerable range of stellar colors, a part of the stars to be observed were selected from Krüger's *Catalog der farbigen Sterne*, and the color numbers, rounded off to the nearest unit, there assigned to the several stars are given below. In some cases it has been necessary to translate a literal symbol into a numerical one. Another portion of the observing programme has been selected from the *Draper Catalogue*, viz., bright stars whose spectrum is there designated by the letter *A*. The color number 0 is assumed to correspond to these stars. Two faint companions

to brighter stars which appear to me distinctly green or bluish green are indicated by the symbol *G*, since Krüger's numerical symbols do not extend to these colors.

Since the present series of observations is purely experimental, I have not sought to multiply observations of the same star, but have for the most part confined myself to two independent determinations of wave-length for each star of the list. For a few stars, however, a larger number of determinations has been made, and I give below the separate results in every case where more than four observations of a single star are available. All observations made on the first fringe are rejected, since the small value of α for that fringe gives very large effect to the accidental errors of observation. The wave-lengths are expressed in millionths of a millimeter, and the number of the fringe from which each determination was made is given.

Vega		Altair		μ Cephei	
572	3	558	3	576	3
560	5	546	3	565	3
559	5	557	5	570	3
554	5	561	5	575	5
564	5	558	7	583	5
549	7	555	7		
570	7				

Vega and Altair are typical white stars, while μ Cephei, the garnet star of W. Herschel, is called the reddest lucid star in the northern hemisphere. The great brilliancy of Vega gives to its fringes a sensible width, which in some measure diminishes the accuracy of the observing.

The differences in the individual determinations above shown are not wholly accidental, and a comparison of all of the data shows the following systematic differences between results derived from different fringes:

Fringes	$\Delta\lambda$	p. e.
7 — 5	$+ 1^{\mu\mu}.0$	$\pm$ 0.8
5 — 3	+ 5 .5	$\pm$ 1.1
3 — 1	— 6 .5	. . . .

These differences are sufficiently explained by the supposition that the measured distance 2θ between the fringes designated by the subscript 3 requires a systematic correction of $+0''.13$. This correction agrees in sign and very approximately in magnitude with systematic corrections to my micrometer measurements derived in connection with observations of double stars, and regarding it as well established, I assume the corresponding correction of $+6^{\mu\mu}.0$ to all wave-lengths derived from fringe 3, and treat the results from the other fringes as free from systematic error.

After the application of this correction, I find from 124 residuals furnished by 51 stars a probable error $r_1 = \pm 3^{\mu\mu}.4$ for a single determination of λ. The measure of precision thus indicated, while very small by comparison with standard determinations of the wave-length of the Fraunhofer lines, is sufficient to furnish some conclusions respecting the influence of color upon effective wave-length, and the data from which these conclusions are to be drawn is set forth in the following table, whose first four columns seem to require no explanation further than the statement that the letters, *A*, *B*, placed after the name of a star denote, respectively, the brighter and fainter components of a double star. In the last three columns λ denotes the mean value of the effective wave-length, *n*, the number of observations included in this mean, and *D. C.* the type of spectrum assigned the star in the *Draper Catalogue*. The character ? appended to these symbols is taken from the *D. C.*, and denotes that the results obtained from different plates were discordant after a second examination. The same symbol in the fourth column is assigned by myself and indicates an uncertain identification of the color.

Star		R. A.		Dec.	Color	λ	n	D. C.
α	Lyrae	18^h	33^m	38 .7	0	562	7	A
α	Aquilae	19	45	8 .6	0	559	6	A
α	Urs. Min.	1	19	88 .7	0	562	2	A
α	Androm.	0	3	28 .5	0	559	2	A
o	Androm.	22	57	41 .8	0	565	2	A
σ	Androm.	0	13	36 .2	0	568	2	A
α	Pegasi	23	0	14 .7	0	560	2	A
γ	Pegasi	0	8	14 .6	0	568	1	A
η	Cassiop.	0	43	57 .2	0?	570	2	F
ψ	Cygni	19	54	52 .0	0?	559	1	A
θ	Cygni	19	32	49 .9	0?	563	1	F?
β	Lyrae	18	46	33 .2	1	563	4	G
γ	Delphini, A	20	42	15 .8	1	573	4	K?
γ	Delphini, B	20	42	15 .8	1?	573	1	...
ι	Aquilae	19	32	1 .5	1	569	2	A
35	Arietis	2	38	27 .3	1	565	2	A
υ	Androm.	1	31	40 .9	1	564	2	F
α	Aquarii	22	1	0 .8	1?	576	2	K?
	Androm.	0	12	38 .1	2	562	2	A
δ	Draco	19	12	67 .5	2 .	564	2	L?
ξ	Pegasi	22	42	11 .7	2	576	4	F
ψ	Aquarii	23	11	— 9 .6	2	575	2	H
	Capricorni	21	17	— 17 .3	3	574	2	H?
5	Lacertae	22	10	39 .2	3	578	2	I
β	Urs. Min.	14	51	74 .6	4	574	2	L?
λ	Pegasi	22	42	23 .0	4	580	2	K (?)
35	Pegasi	22	23	4 .2	4	580	2	K
ε	Pegasi	21	39	9 .4	4	564	2	K
ι	Cephei	22	46	65 .7	4	580	2	I?
λ	Androm.	23	33	45 .9	4	576	2	K
ζ	Aurigae	4	56	40 .9	4	564	2	I?
ζ	Cephei	22	7	57 .7	5	574	2	K?
1	Lacertae	22	12	37 .2	5	578	3	I?
3	Lacertae	22	20	51 .7	5	577	2	I
11	Lacertae	22	36	43 .8	5	574	2	H
β	Androm.	1	4	35 .1	5	570	2	K?
γ	Androm., A	1	58	41 .8	5	568	2	K
γ	Androm., B	1	58	41 .8	G	564	1	...
γ	Aquilae	19	42	10 .4	6	573	2	K
τ	Aquarii	22	44	— 14 .1	6	581	2	M?
λ	Aquarii	22	47	— 8 .1	6	579	4	M?
3	Aquarii	20	42	— 5 .4	6	570	2	...
$α^2$	Capricorni	20	12	12 .8	6	572	2	H?
30	Piscium	23	57	— 6 .6	6	580	2	H
δ	Sagittae	19	43	18 .3	6	573	2	M?
γ	Sagittae	19	54	19 .2	7	575	2	K
β	Pegasi	22	59	27 .5	7	572	2	M?
ψ	Pegasi	23	53	24 .6	7	580	2	H
β	Cygni, A	19	26	27 .7	7	571	3	Q?
β	Cygni, B	19	26	27 .7	G	574	2	A?
5	Lacertae	22	25	47 .2	7	577	2	H?
α	Orionis	5	49	7 .4	7	570	2	M?
R	Lyrae	18	52	43 .8	7	570	3	M?
α	Tauri	4	30	16 .3	7	570	4	K?
μ	Cephei	21	40	58 .3	8	577	5	M?

Even a casual inspection of these values of λ_0 will suffice to show a progressive increase in the numbers, but this sequence is best brought out by taking mean values for groups of stars selected with reference either to the color number or to the type of spectrum. Thus, with respect to color we have

Color No.	Stars	λ
0	11	$563^{\mu\mu}.2$
1–2	11	569 .1
3–4	9	574 .4
5–6	14	573 .8
7–8	9	573 .6

With respect to the type of spectrum, the symbols of the *Draper Catalogue* being translated in accordance with the introduction to that volume, we have

Class	Stars	λ
I	13	564.0
II	31	572.6
III	7	574.6

These tables agree in differentiating the white stars of the Sirian type from the yellow or solar stars by a much wider interval than separates the latter from the red stars with banded spectra. Indeed, the difference in the values of λ_0 coresponding to the last two classes but little exceeds the probable error of the tabular numbers. In view of the limited number of stars observed it will be best to restrict conclusions from the preceding data to the statement that the effective wave-length of the light of stars which are distinctly colored is approximately $9^{\mu\mu}$ greater than that of white stars; and that stars of the deepest red color do not sensibly differ in effective wave-length from those of a yellow hue.

If we adopt Kayser and Runge's value for the atmospheric dispersion of light (*Astronomy and Astrophysics*, No. 115) it may readily be shown that at a zenith distance of 45° the difference of $9^{\mu\mu}$ in effective wave-length corresponds to a difference of about $0''.03$ in the refraction, and this may obviously be neglected in all cases save those in which the utmost possible precision is required.

The observations above set forth are to be considered as a first attempt, with homemade apparatus, at applying interference methods to the problem in hand. The screen was cut from a piece of pasteboard, and the adopted average width of the slits, $a = 27^{mm}.0$, is uncertain to the extent of $0^{mm}.1$ or $0^{mm}.2$ corresponding to something less than 1 per cent. in the absolute values of the wave-lengths. The relative values are, however, free from this source of error, since the same screen was used in all of the observations.

A serious limitation upon the more extended use of the method is the difficulty attending its application to faint stars. With the apparatus which I have employed the sixth or possibly the seventh magnitude constitutes the limit at which the third fringe is bright enough to be satisfactorily measured, and if the observations are to be extended below this limit the first fringe must be used and a large part of the precision of the results sacrificed.

Washburn Observatory,
November 24, 1896.

REMARKS ON THE ARTICLES OF MR. E. J. WILCZYNSKI IN THIS JOURNAL VOL. IV. NO. 2.

By Paul Harzer.

In the first of these articles my mathematical treatment of the solar rotation in *A. N.* 3026 is accused of lacking vigor. On the contrary I shall show that the deductions of Mr. Wilczynski are quite erroneous.

The principal error is the conclusion drawn from equations (6), that ω^2 does not depend upon c and depends only upon $\sqrt{a^2+b^2}$. This conclusion is tenable only in the case of the symbol

$$dP = \frac{dp}{\rho}$$

being really integrable. But in general from equations (6) or, more clearly written, from

$$\frac{dV}{da} - \frac{1}{\rho}\frac{dp}{da} = -\omega^2 a \qquad \frac{dV}{db} - \frac{1}{\rho}\frac{dp}{db} = -\omega^2 b \qquad \frac{dV}{dc} - \frac{1}{\rho}\frac{dp}{dc} = 0$$

we deduce the relations

$$\frac{d^2V}{da\,db} - \frac{1}{\rho}\frac{d^2p}{da\,db} = -a\frac{d\omega^2}{db} - \frac{1}{\rho^2}\frac{d\rho}{db}\frac{dp}{da} = -b\frac{d\omega^2}{da} - \frac{1}{\rho^2}\frac{d\rho}{da}\frac{dp}{db}$$

$$\frac{d^2V}{da\,dc} - \frac{1}{\rho}\frac{d^2p}{da\,dc} = -a\frac{d\omega^2}{dc} - \frac{1}{\rho^2}\frac{d\rho}{dc}\frac{dp}{da} = -\frac{1}{\rho^2}\frac{d\rho}{da}\frac{dp}{dc}$$

$$\frac{d^2V}{db\,dc} - \frac{1}{\rho}\frac{d^2p}{db\,dc} = -b\frac{d\omega^2}{dc} - \frac{1}{\rho^2}\frac{d\rho}{dc}\frac{dp}{db} = -\frac{1}{\rho^2}\frac{d\rho}{db}\frac{dp}{dc}$$

and hence

$$a\frac{d\omega^2}{db} - b\frac{d\omega^2}{da} = \frac{1}{\rho^2}\left(\frac{d\rho}{da}\frac{dp}{db} - \frac{d\rho}{db}\frac{dp}{da}\right)$$

$$\frac{d\omega^2}{dc} = \frac{1}{a\rho^2}\left(\frac{d\rho}{da}\frac{dp}{dc} - \frac{d\rho}{dc}\frac{dp}{da}\right) = \frac{1}{b\rho^2}\left(\frac{d\rho}{db}\frac{dp}{dc} - \frac{d\rho}{dc}\frac{dp}{db}\right)$$

Therefore in general neither $a\frac{d\omega^2}{db} - b\frac{d\omega^2}{da}$ nor $\frac{d\omega^2}{dc}$ are vanishing.

Another error involves the formulæ (5) as they contradict the supposition that a, b, c represent the values of x, y, z, for $t = 0$. The correct formulæ are:

$$x = a \cos \omega t - b \sin \omega t \qquad y = a \sin \omega t + b \cos \omega t \qquad z = c$$

The equations (6) remain unaltered by introducing these formulæ into equations (1).

By means of the erroneous formulæ (5) Mr. Wilczynski concludes that all conditions are satisfied, it being easy to prove that D vanishes. He is here overlooking the fact that a vanishing value of D is physically impossible, D representing the relation of the elementary volumes for the times $t = t$ and $t = 0$. The correct formulæ for x, y, z, giving

$$D = \Delta + \left(a \frac{d\,\omega}{d\,b} - b \frac{d\,\omega}{d\,a}\right) t,$$

the condition of continuity requires the expression

$$\rho \left(\Delta + \left(a \frac{d\,\omega}{d\,b} - b \frac{d\,\omega}{d\,a}\right) t \right) = \rho \left(\Delta + \frac{1}{2\rho^2 \omega} \left(\frac{d\,\rho}{d\,a}\frac{d\,p}{d\,b} - \frac{d\,\rho}{d\,b}\frac{d\,p}{d\,a} \right) t \right)$$

to be invariable for a moving elementary mass.

This condition is fulfilled only in consequence of certain suppositions regarding the constitution of the revolving mass, for instance the supposition that the density and the pressure are the same at all similarly situated points of all plane sections across the axis of rotation. Then ρ does not change for a moving elementary mass and ρ, p and ω^2 depend only upon $\sqrt{a^2 + b^2}$ and $\sqrt{a^2 + b^2 + c^2}$; but even in this special case the value of $\frac{d\,\omega^2}{d\,c}$ does not vanish.

I think that the vanishing value of $\frac{d\,\omega^2}{d\,c}$ must have led Mr. Wilczynski to the objection against my treatment of the problem. But the error is his, not mine.

In view of these facts Mr. Wilczynski's considerations cannot be maintained; for if they are legitimate they ought to be limited to cases of integrable values of $\frac{dp}{\rho}$, for instance to incompressible fluids or to gases at *constant* temperature, *i. e.*, to cases the existence of which we have no reason to assume anywhere in nature.

GOTHA, October 10, 1896.

RESEARCHES ON THE ARC-SPECTRA OF THE METALS. III. COBALT AND NICKEL. III.[1]

By B. HASSELBERG.

SPECTRUM OF NICKEL.

Nickel λ	R.	I Ni	I ☉	REMARKS	Liveing and Dewar
3458.59		4	4	Very diffuse. Reversed.	58.45
61.78		4	4	Very diffuse. Reversed.	61.66
62.95		1	2	Ni ?	
67.63		2.3	2	Sharp.	67.35
69.64		2.3	3	Sharp.	69.45
72.68		3.4	3	Diffuse. Reversed.	72.45
78.48		1	1.2		
79.43		1	1		
80.36		1	1		
86.04		2.3	2		85.75
——	3486.04				
93.10		4.5	4	Very diffuse. Reversed.	92.85
96.50		1	1		
3501.00		3	2.3		00.55
02.76		2	2		
07.85		2	2	Sharp.	07.86
10.47		4	4	Diffuse. Reversed.	10.26
——	3510.99				
14.06		2.3	2.3		
15.17		4.5	4	Very diffuse. Reversed.	14.96
16.35		2	1.2		
18.80		2	2		18.56
19.90		3	2.3		19.66
23.19		1.2	1.2		
24.65		5	4	Very diffuse. Reversed.	24.46
28.13		2.3	2		
29.03		1.2	1		
29.76		1	1		
30.73		1.2	1.2		30.47
33.89		1	1	Diffuse.	
——	3540.27				
48.34		2.3	2.3	Also Mn.	48.07
51.66		2.3	2		51.37
53.63		2	2		53.37
——	3558.67				
60.08		1	1		
61.91		2	1.2	Very sharp.	61.67
66.50		4.5	4	Very diffuse. Reversed.	66.27

[1] Continued from p. 306.

Nickel λ	R.	i Ni	i ☉	Remarks	Liveing and Dewar
3571.99		3.4	3	Diffuse. Reversed.	71.78
77.37		1	1		
——	3583.48				
88.08		2.3	2.3	Very sharp.	
97.84		3.4	3.4	Diffuse.	97.58
3602.41		2.3	2		
——	3605.63				
07.02		1	1		
09.44		2.3	2		
10.60		4	3	Reversed.	10.38
11.58		1	1		
12.86		3.4	2.3		12.68
19.52		5	5	Very diffuse. Reversed.	19.38
24.87		3	2.3	Very sharp. ☉ line double { 24.87 Ni. / .97 Fe, Ti. }	24.68
30.04		1.2	1 2		
35.10		2	2	Very sharp. ☉ line a close double.	35.49
——	3635.62				
41.78		1.2	1.2		
42.58		1	—	{ Ni ?	
44.13		1	—		
——	3658.69				
62.10		2	1.2	Very sharp.	
64.24		3	2.3	Very sharp. ☉ double { 64.16 Fe. / .24 Ni.	63.99
68.35		1	1.2		
69.38		2	2	Very sharp. ☉ double { 69.30 Fe. / .37 Ni.	
70.57		2.3	2.3	Very sharp.	70.29
74.28		3.4	2	Very sharp. ☉ double { 74.18 Fe. / .28 Ni.	73.99
83.65		1	?		
——	3684.26				
88.58		2.3	2.3	Very sharp.	88.19
94.10		2	2.3	☉ line a close double { 94.10 Ni. / .20 Fe.	
97.04		1	1		
3713.49		1	1		
13.87		1	1		
15.61		1.2	2		
——	3716.58				
22.63		3	4	Ni line on the red edge of the ☉ line 22.70 Fe, Ti.	
24.95		1.2	1.2		24.80
29.05		1	2		
30.88		1.2	2		
36.94		3.4	3.4	Very sharp.	36.70
39.36		2.3	2	☉ line triple { 39.26 Fe. / 36 Ni. / .46 Fe.	
39.89		1	1.2		
——	3743.50				

Nickel λ	R.	I Ni	☉	Remarks	Liveing and Dewar
3744.68		2.3	2	Very sharp.	
49.15		2	2.3	Very sharp. ☉ line probably double.	
62.76		2	1		
69.58		1	1.2		69.50
72.70		2.3	2	Sharp.	
——	3774.48				
75.71		4.5	2.3		75.62
78.22		1.2	1.2		
83.67		4	2.3		83.62
92.48		2.3	2	Very sharp.	
93.75		3	2	Very sharp.	
	3805.49				
3807.30		4	3		07.22
11.46		1	1.2	☉ line a close double { 11.46 Ni. .56 Ti.	
29.49		2.3	–		
31.82		3	3		
32.44		2.3	4		32.32
33.02		2	1.2		
——	3836.23				
44.40		1.2	2	Very diffuse.	
44.71		1.2	1		
58.40		4.5	3	Reversed.	58.42
63.21		2.3	1.2		
——	3864.44				
71.73		1.2	1		
——	3886.43				
89.80		2.3	2	Very sharp.	
3905.07		1.2	4	Probably a foreign line.	
09.10		1.2	1.2	Very diffuse.	
12.44		1.2	1.2	Very diffuse.	
13.12		2	1.2		
14.65		1	?		
——	3916.87				
44.25		3.4	–	Very diffuse.	
——	3954.00				
54.61		1.2		Very diffuse.	
70.65		2		Very diffuse.	
72.31		2.3	2		
73.70		4	2.3	☉ line a close double { 73.70 Ni. .81 Fe.	
74.83		2		Very diffuse.	
——	3977.89				
84.18		2		Very diffuse.	
94.13		2	–	Very diffuse.	
95.45		3.4	2.3		
——	4003.92				
4006.30		2	1.2		
10.14		1.2	?		
17.65		2		Very diffuse.	
19.20		1.2	1.2		
22.20		1	–		

Nickel λ	R.	i Ni	i ⊙	Remarks	Thalén
4025.26		1.2	1.2		
——	4034.64				
46.91		1	—		
57.45		1	—		
——	4062.60				
64.55		2	—		
69.39		1	—		
73.08		1	—		
75.05		1.2		Sharp.	
75.75		1.2		Diffuse.	
86.30		1	1		
——	4088.72				
4104.37		1	—		
16.14		2	1		
21.48		3	3	Sharp. 21.41 Cr.	
——	4121.97				
23.96		1			
38.67		1	?		
42.34		1	1.2		
42.47		2	1.2		
43.12		1	1		
50.55		1.2	1 2	⊙ has 50.48 Fe.	
——	4157.95				
64.82		1	1	Sharp.	
67.16		1.2	—	Diffuse.	
84.65		1.2			
——	4185.06				
95.71		2.3	1.2	⊙ a close double $\left\{\begin{array}{l}\text{95.71 Ni.}\\ \text{.77 Fe.}\end{array}\right.$	
4200.61		2	1.2	Sharp.	
01.88		2.3	1.2	Sharp.	
02.33		1	—		
21.87		1	—		
——	4231.15				
31.23		2	—		
36.55		1.2	—		
52.25		1	1		
——	4254.50				
84.83		2.3	1.2		
88.16		3.4	2	⊙ double $\left\{\begin{array}{l}\text{88.05}\\ \text{.15}\end{array}\right.$	
——	4293.25				
96.06		3	1		
97.15		1	2		
98.68		1.2	1		
98.94		1	1.2		
4307.40		1.2	1.2		
——	4308.03				
25.49		1.2	1.2	Diffuse.	
25.75		2.3	1.2	Sharp.	
30.85		2.3	1.2	Intensity of the Ni line variable.	
31.78		3			

Nickel λ	R.	i Co	i ⊙	Remarks	Thalén
——	4343.39				
4356.07		2	1.2	Diffuse.	
59.73		3	2	Sharp. ⊙ line the middle line of a Close triplet. Cr has 59.78, Ba 59.80.	
68.45		2	1		
70.21		1.2	1	Diffuse. ⊙ perhaps double.	
——	4370.10				
83.05		1			
84.68		2.3	1.2		
86.62		1.2	?	Diffuse.	
90.00		2	1		
90.47		1.2	?	Diffuse.	
98.78		1	1		
99.75		2	1		
4401.02		2	1.2		
01.70		4.5	2	⊙ line double $\left\{\begin{array}{l}01.60\\ \quad .70\ \text{Ni}\end{array}\right.$	
——	4407.85				
10.70		2.3	2	Diffuse.	
23.24		1.2	1		
——	4435.13				
37.17		2.3	2		
37.75		2			
41.64		1	—		
42.61		2			
50.20		1			
50.44		1	—		
——	4456.05				
59.21		4.5	2	⊙ line double $\left\{\begin{array}{l}59.20\ \text{Ni}\\ \quad .30\ \text{Fe}\end{array}\right\}$, (K.—R:59.30)	
62.59		4	2		
63.57		2	1.2		
66.54		2	1		
70.61		4	2.3		
81.30		1	1.2	Diffuse.	
90.71		2	1	Diffuse.	
——	4494.17				
4506.53		1	—		
——	4508.46				
13.20		2	1		
20.20		2.3	1	Very sharp.	
——	4531.40				
47.14		2	2	⊙ has $\left\{\begin{array}{l}47.15\ \text{Ni}\\ \quad .25\ \text{Fe}\end{array}\right\}$ (K.—R:47.20)	
47.44		2.3	1.2		
51.45		2	1		
53.37		1.2	1		
——	4554.21				
60.10		2	1		
67.59		1	—		
80.77		1.2	1.2		
——	4588.38				

Nickel λ	R.	Co[1]	⊙	Remarks	Thalén
4592.69		3.4	2.3	⊙ has { 92.70 Ni / .80 Fe } (K.—R:92.81)	
95.07		2	1.2		
96.11		2	—	Diffuse.	
4600.51		3	2		
05.15		4	2.3		
06.37		2.3	1.2		
14.85		1	1		
18.22		1.2	1	⊙ line double { 18.15 / .22 Ni	
——	4611.45				
47.47		1.2	1		
48.82		3	2.3		
55.85		1+	1		47.88
67.16		1.2	1.2		
67.96		2	1.2		
——	4668.30				
75.80		1	1		
86.39		2.3	2	Sharp. Cr. has 86.38; lines probably divided	
——	4686.39				
4701.52		1	1.2		
01.72		2	1.2		
——	4703.18				
03.96		2.3	2	Diffuse.	
12.24		1	1		
14.59		4.5	3		14.54
15.93		3	2		
——	4727.63				
28.06		1	1		
29.50		1	1		
32.00		2	1.2		
32.66		2	1.2		
52.30		1.2	1.2	Coincides with a Cr line. The other strong lines of Cr in this neighborhood are missing.	
52.58		2	1.2		
——	4754.23				
54.95		1.2	1.2		
56.70		3	2		55.84
62.78		1.2	1.2		
64.07		2	2		
73.55		1	1		
	(4780.10)			([1])	
86.42		1	1.2		
86.66		3	2.3		86.64
92.98		1	1.2		
——	4805.25				
4807.17		2	2		
09.05		1	1		
12.15		1	1		
14.77		1	1		
17.97		1	1.2		
21.29		1	1.2		

[1] The lines λ 4780.10, 4950.25, and 5227.40 are taken from Rowland's map of the solar spectrum.

Nickel λ	R.	i Co	⊙	REMARKS	Thalén
—	4824.33				
4829.18		3	2.3		29.30
31.30		2.3	2.3		31.10
22.86		1.2	2		
38.80		2	2		
43.27		1	1.2		
52.70		1.2	2	Diffuse.	
55.57		3	2.3		55.60
57.57		1.2	2		
—	4859.93				
64.11		1.2	1	Diffuse.	
64.46		1	1.2	Diffuse.	
66.42		3.4	2		66.20
70.97		2	2	Cr has a strong line at 70.96; divided from Ni, and λ Cr < λ Ni	
73.60		2	2		73.80
74.95		1	1		
87.16		1.2	2		
	4890.94				
4904.56		3.4	2.3		04.70
12.22		1.2	1.2	Diffuse.	
14.15		2	1.2	Diffuse.	
18.53		2.3	2	Sharp.	18.40
18.86		1	1.2		
25.74		1.2	1.2		
—	4934.25				
36.02		2	2	Sharp.	35.90
37.51		2	2	Very diffuse.	
45.63		1.2	2	Diffuse.	
	(4950.25)				
46.20		1	1		
53.34		1.2	1.2		
71.54		1.2	2		
—	4973.27				
76.54		1	1.2		
80.36		3.4	2.3		80.40
	4981.92				
84.30		3.4	2.3		84.10
97.04		1	1.2	Diffuse.	
98.42		2	2		
5000.48		2.3	2	Diffuse. ⊙ line double.	
03.92		1	1.2		
10.22		1	1		
11.11		1.2	1.2	Diffuse.	
12.62		2	2	Sharp.	
17.75		3.4	2.3		17.40
18.50		2	2	Very diffuse.	
—	5020.21				
35.55		5	2.3		35.50
38.80		2	2		
42.35		2.3	2	Diffuse.	
49.01		2.3	2	Diffuse. Cr has 48.96, distinctly divided.	

Nickel λ	R.	i Co	⊙	Remarks	Thalén
5051.74		1	1.2	Very diffuse. ⊙ line double { 51.75 .85	
58.22		1	1		
——	5060.25				
80.16		1.2	1.2		
80.70		5	2.3		80.70
81.30		5	2.3	Diffuse.	81.56
82.55		2.3	2	Diffuse.	
——	5083.53				
84.27		4	2.3	Diffuse.	
88.74		1	1.2		
89.13		1	1.2		
94.61		1	1.2		
97.06		2	2	Diffuse.	
99.50		2.3	2.3	Sharp.	99.46
5100.13		3.4	2.3	Diffuse.	00.66
03.13		2	1.2		
——	5110.57				
15.55		4	2.3	Very sharp.	16.00
21.74		1.2	?		
25.39		2.3	2.3	⊙ line a close double.	
29.52		3	2.3		
30.55		1	1		
31.94		1.2	1.2	Diffuse.	
37.23		4	2.3	Very sharp.	37.91
——	5141.92				
42.96		3.4	2	Diffuse.	43.11
46.64		4	2	Diffuse.	46.81
53.43		2	2		
55.34		2	2	Diffuse.	
55.92		3.4	2.3	Diffuse.	56.21
58.20		1	1		
——	5167.57				
68.83		2.3	2		69.41
76.73		2	2		76.71
84.78		1.2	1.2		
86.80		1	1		
——	5188.95				
92.70		1	?		
97.40		1	1		
——	5198.89				
5216.72		1	1		
20.51		1	1		
——	(5227.40)				
68.59		1	1		
——	5270.49				
5371.64		2.3	2		
——	5379.77				
88.71		1	1		
92.68		1	1		
——	5397.34				
5411.50		2	1.2	Sharp.	
——	5415.42				

Nickel λ	R.	Co	⊙	Remarks.	Thalén
5424.85		2	1.2		
—	5434.74				
36.10		2.3	1.2	Very sharp.	
62.71		2	1.2		
—	5466.61				
68.42		1	1		
77.13		5	3		77.20
95.20		1.2	1	Sharp.	
—	5497.73				
5504.50		1.2	2		
10.28		2.3	1.2	Sharp.	
—	5513.21				
53.97		2	1.2	Sharp.	
—	5555.11				
78.98		2.3	1.2		
—	5582.19				
88.12		2.3	1.2	Sharp.	
89.63		2	1	Diffuse.	
92.44		3.4	2	Sharp. ⊙ line a close double. Coincident with red component.	
94.00		3	1.2		
5600.29		2	1.2		
15.00		3	1.2	Sharp.	
—	5615.88				
25.56		3	1.2		
28.62		1.2	1		
37.32		2	1.2		
39.02		1.2	—		
42.08		1.2	1		
43.31		1.2	1	Diffuse.	
—	5645.83				
49.90		2.3	1.2		
64.28		2.3	1.2		
70.22		2	1		
—	5675.65				
82.44		3.4	1.2	Diffuse.	
95.22		3	1.2	Diffuse.	
—	5701.77				
5709.80		3.4	2		
12.10		3	2		
15.31		3	2	Also a Ti line.	
—	5715.31				
48.57		1.2	1.2		
54.86		3	2.3		
61.10		2.3	1.2		
—	5763.22				
96.35		1	1		
5805.45		2	2		
	5806.05				
47.26		1	1.2		
58.03		2	2		57.72
—	5859.81				
93.13		2.3	2		93.22
—	5896.15				

As the last column of this catalogue shows, the number of lines which Thalén observed in the spectrum of the induction spark is quite small; still it is sufficiently large to afford a basis for estimating the accuracy of his measurements. If the differences between our wave-length values are formed it will be found that they have a wholly accidental character, and that the probable error[1] of one of Thalén's wave-lengths is:

From observations of the cobalt spectrum, $s_{,} = \pm 0.32$ tenth-meters.
From observations of the nickel spectrum, $s_{,,} = \pm 0.24$ tenth-meters.

Among the lines of cobalt there is one, λ 5359.4, for which the difference *H-Th* reaches the abnormally high value of -1.34 tenth-meters. If this exceptional case is excluded, then $s_{,} = \pm 0.26$ tenth-meters, a value which is in complete agreement with the probable error of the observations of the nickel spectrum, and with that of the observations of titanium already discussed. It would be difficult to find any observations made at that time which are comparable, with respect to accuracy, to the observations of Thalén.

The differences between my wave-lengths and those of Liveing and Dewar, in the ultra-violet part of the spectrum measured by both of us, run somewhat differently. They are positive almost throughout, corresponding to a systematic deviation which is in the mean

$$H - LD = + 0.12 \text{ tenth-meters, for cobalt,}$$
$$= + 0.19 \text{ tenth-meters, for nickel.}$$

Since, however the wave-lengths of Liveing and Dewar are referred to Rowland's earlier wave-length of the *D* lines, for which Bell subsequently found the correction + 0.06 tenth-meters, it is necessary, in order to reduce the above differences to the wave-length system of my observations, to apply the correction $- 0.06$. Thus they finally become

$$H - LD = + 0.06 \text{ tenth-meters, for cobalt,}$$
$$= + 0.13 \text{ tenth-meters, for nickel;}$$

[1] The probable error of my own observations is included in these values; but since this hardly exceeds ± 0.02 tenth-meters, the above figures also give the probable error of Thalén's measures with reference to Rowland's scale.

or, taking the mean,

$$H - LD = + 0.10 \text{ tenth-meters.}$$

This agreement is certainly to be regarded as a very satisfactory one.

The existence of cobalt and nickel in the Sun's atmosphere is a fact which has long been established. It is at once apparent on comparing the third and fourth columns of the table. If we arrange the lines in groups, according to their intensity, we obtain the following table showing the number of coincidences and non-coincidences for each group:

COBALT.

i	Coinc.	Non-Coinc.
1–1.2	73	150
2–2.3	143	106
3–3.4	76	17
4–4.5	29	2
5–.6	5	0

NICKEL.

i	Coinc.	Non-Coinc.
1–1.2	118	34
2–2.3	114	11
3–3.4	45	2
4–4.5	22	0
5–6	6	0

It will be seen that the lines of nickel, especially in the weaker classes, are represented in the solar spectrum with considerably greater completeness than those of cobalt. Thus, while 86.5 per cent. of all the observed nickel lines are represented by solar lines, the percentage for cobalt is only 54.3. If we exclude the weakest class of lines, on the ground that it is more likely than others to contain foreign lines due to impurities, the percentages become respectively 93 and 66, and the significant difference between the two metals in this respect therefore still remains. This seems to indicate that there is more

nickel than cobalt in the solar atmosphere. In order to test this supposition I have arranged the coincident solar lines in groups, according to their estimated intensities, giving for each group the number of coincidences and the percentage which it forms of the total number of coincidences.

I ⊙	Co	Ni
1	120 = 37 p.c.	70 = 23 p.c.
1.2	74 = 22.5 "	96 = 31.5 "
2	84 = 25.0 "	77 = 25.2 "
2.3	31 = 9.4 "	40 = 13.1 "
3	15 = 4.6 "	9 = 3 "
3	2 0.6 "	13 = 4.2 "

This table shows that of the coincident solar lines the weakest are represented more numerously by cobalt than by nickel, while for the stronger lines just the opposite is true. The assumption of a more intense absorption by nickel than by cobalt seems, therefore, to have some foundation in this fact, and since, on account of the approximate equality of their atomic weights, these two metals must exist in the Sun at the same temperature-level, the stronger absorption on the part of the nickel vapor would represent a greater quantity of that substance.

Minor Contributions and Notes.

BENJAMIN APTHORP GOULD.

Benjamin Apthorp Gould was born in Boston, September 27, 1824. After his course in Harvard College, where he graduated with distinction in 1844, he went to Europe and studied under Gauss, Encke, Struve, Peters, Hansen and Argelander. As Dr. Chandler has recently pointed out,[1] the influence which he exercised from that time forward contributed in a marked degree to the building up of American astronomy. In 1852 he was placed in charge of the longitude determinations of the Coast Survey, where he remained until 1867. While engaged in this work he found time to organize the Dudley Observatory at Albany, and from 1855 to 1859 he not only directed this institution, but carried it on at his private expense. In the ten years that followed he published much valuable work, including a discussion of the places and proper motions of circumpolar stars, since used as standards in the Coast Survey and, after revision in 1861, in the American Ephemeris; a reduction of D'Agelet's observations; reductions of the greater part of the observations made at the United States Naval Observatory since its establishment; reductions of the observations made by the expedition to Chili to determine the solar parallax; determination of the difference in longitude of European and American stations, made with the aid of the Atlantic cable; and the first reductions of astronomical photographs — Rutherfurd's negatives of the Pleiades. He also determined the right ascensions of all stars to the tenth magnitude within one degree of the pole with a transit instrument at his private observatory in Cambridge.

In 1865 he determined to extend his observations to the stars of the southern hemisphere. The expedition, organized at first with private assistance, finally resulted in the establishment of the Argentine National Observatory at Cordoba. The *Uranometria Argentina*, the zone observations of stars between 23° and 80° south declination, and the independent series of meridian circle observations for the

[1] In an appreciative paper on the life and work of Dr. Gould published in *Science*, December 18, 1896, from which many of the facts in the present notice are derived.

General Catalogue of 32,448 stars remain as lasting testimonials to the great work accomplished by Dr. Gould and his assistants. While at Cordoba he also secured some 1400 negatives of stellar clusters, the measurement and reduction of which he had practically completed at the time of his death.

The *Astronomical Journal* was established by Dr. Gould in 1849, and continued until 1861, when he was forced to suspend its publication. Fortunately for American astronomy it became possible to reëstablish the *Journal* in 1885, since when it has appeared regularly. Devoted exclusively to the publication of original investigations, the *Astronomical Journal* has performed a great service for science in the United States. It is satisfactory to know that it will be continued under the able management of Dr. S. C. Chandler, assisted by Professor Asaph Hall and Professor Lewis Boss.

Dr. Gould's numerous services to science received richly deserved recognition from many learned societies. His sudden death on November 26, 1896, the result of a fall at his home in Cambridge, will be widely mourned.

PHOTOGRAPHIC STUDIES OF THE MOON AT THE PARIS OBSERVATORY.

In a series of papers[1] published in the *Comptes Rendus* at various times during the last two years, MM. Loewy and Puiseux have given an account of the researches in lunar photography which they have carried on with the aid of the great equatorial coudé at Paris. Some of these papers are devoted principally to a description of the instrument and its adjustment, others to general remarks on the subject of lunar photography and the difficulties which must be overcome in order to realize the full capabilities of the apparatus at their command. An interesting point in this connection is the method which they use for getting rid of the motion of the image in declination, by choosing for exposure (with the aid of a previously prepared table), times when the Moon's motion in declination is neutralized by the change of parallax. The rate of the driving clock is controlled by the observer, without stopping the clock, by means of a sliding weight on the pendulum. In some places the authors give the conclusions to which they have been led, by a study of their photographs, as to the nature and prob-

[1] *C. R.* **119**, 130-135, 254-259, 1894; **121**, 6-12, 79-85, 1895: **122**, 967-973, 1896.

able origin of the characteristic features of the Moon's surface. The last published paper (*C. R.* **122**, 967–973, 1896) contains a somewhat more elaborate statement of these views, which differ in a number of important particulars from those of other observers. They resemble in many respects the views of Suess.[1]

This paper, when presented to the French Academy of Sciences, was accompanied by the first six sheets of a new photographic atlas, the scale of which is approximately 1 : 1,300,000. The corresponding lunar diameter is about $2^m.6$, and the scale, therefore, considerably exceeds that of Schmidt's map (2^m). Since the diameter of the image in the focus of the equatorial coudé is $0^m.18$, the map represents an enlargement of 14 or 15 times. The enlargement is, however, not quite the same for all the plates, and a scale for each sheet would have added materially to the usefulness of the atlas.

The beautiful plates are heliogravures, prepared from enlargements on glass of the same size as the plates themselves ($0^m.48$ by $0^m.58$). The process is an expensive one, but it yields the best results. It is said that the grain of the negatives is finer than that of the plates used in America, and this is probably the case, as, judging by the relation between aperture and exposure, the plates seem to be slower. It may further be noted that the great focal length (18^m) of the equatorial coudé makes it specially suitable for the purposes of lunar photography, since with a large image the granulation of the negative is relatively less important than with a small one. The impressive size and fine definition of the unenlarged image obtained with the equatorial coudé are well shown by the exquisite heliogravure of the half Moon which forms the first plate of the atlas.[2]

We may now consider the explanation of the lunar markings which is proposed by the authors, and which forms part of the text accompanying the sheets. Suess remarks in the paper already referred to, that no selenographic theory can be established if it is not admitted that the forces which are revealed to us by their effects on the Earth equally exert their action on the Moon, and that the crusts of the two bodies are composed of similar materials. This reasonable hypothesis is accepted by Loewy and Puiseux as the basis of their own theory. So far as the character of the crust is concerned, the principle of Suess

[1] *Sitz. d. K. Akad. d. W. Wien*, February 1, 1895. English abstract in *Pub. A. S. P.*, No. 42, 7, 139–148, 1895.

[2] See also the Annual Report of the Observatory of Paris for the year 1895.

need not be too rigidly applied. An assumption of identity in the materials of the crusts of the two bodies would oblige us to regard the density of the Moon as uniform, since the density of the volcanic rocks of the Earth is about the same as the mean density of the Moon. The lunar crust may be supposed to consist of materials considerably lighter than the ordinary volcanic rocks of the Earth without affecting the reasonableness of the assumption. In any case, the adoption of the hypothesis rules out all but a limited number of possible explanations of lunar formations.

The theory of Loewy and Puiseux is a modified form of the volcanic theory, and their attention is first given to an inquiry into the possibility of present or past eruptive action. The principal arguments opposed to the volcanic hypothesis may be reduced to the three following: (1) the annular formations on the Moon are entirely distinct, by reason of their form and size, from all known craters on the Earth; (2) every volcanic eruption is necessarily accompanied by an abundant disengagement of gas and aqueous vapor; (3) the Moon has neither a liquid surface nor an appreciable gaseous envelope, and its surface features have not been modified by the circulation of water. These objections are considered by the authors, their conclusion being that the conditions necessary for volcanic action probably existed in the past, if they do not exist now; moreover, they do not necessarily imply the existence of an atmosphere of considerable refractive power. The ordinary cause of explosions is the presence of water at great depths, and on the Moon the quantity of imprisoned vapors must have been greater than on the Earth, by reason of the more rapid cooling of the surface.

The authors believe, however, that there is some evidence of the present existence of a lunar atmosphere. Bessel's negative result has been generally accepted, yet modern observations have invariably shown that the Moon's diameter deduced from occultations of stars is smaller than that obtained from meridian transits. If they say, the values given by the two methods were definitive, the reality of a lunar atmosphere would be proved; but they do not mention the fa that there are reasons why the two methods should give results which differ in the manner actually observed,—reasons which have no connection with the possible existence of an atmosphere. Irradiation, diffraction, and imperfect definition arising from a variety of causes, all tend to increase the measured diameter of a bright object. This has been well

pointed out in a recent article by Mr. Campbell.[1] The difference in question, which is only from $1''$ to $2''$, is very probably thus fully accounted for. A more reliable test for the presence of an atmosphere would seem to be its effect on the outline of a planet during an occultation, or on the direction of the Sun's limb during an eclipse, and in such occurrences the evidence is generally negative, although there are some exceptions on record. The question, however, is not an important one for the argument, since it may be conceded that an atmosphere probably existed under past conditions, even if there is none at the present time. An examination of all the conditions leads the authors to conclude on *a priori* grounds, that the Moon was once specially well fitted for the display of eruptive phenomena.

In framing their hypothesis MM. Loewy and Puiseux have used all the well-known data, and to a considerable extent, it would appear, data which they have obtained from a study of their own photographs. The facts which they regard as most significant are as follows:

"(1) The mountainous regions of the Moon are traversed for great distances by straight grooves (rills), in the course of which numerous eruptive funnels have been formed. (2) These rills, which are distributed in several parallel systems, have frequently served to limit the contour of the craters, and have therefore contributed toward giving them their polygonal shape. (3) The great craters have a tendency to occur in groups of two, three or four, arranged in certain definite directions which agree with those of the rills in the same region; (4) it is not rare to find them surrounded by a ring of secondary craters; the top of the rampart is a favorite place for the subsequent formation of eruptive funnels and centers of explosion. (5) When several craters overlap, the smallest is ordinarily the deepest, and is the only one which has a complete wall and a central mountain. (6) In the deepest craters the interior is generally studded with numerous hills grouped around a central mountain. If the bottom is less deeply depressed it appears as a plain, from which the central peak alone emerges. If it is still higher the central peak disappears, and the whole interior has a uniform aspect entirely similar to that of the seas. A final category is formed by annular forms without an interior depression, where the rampart alone exists, often incomplete and half submerged. (7) The great plains known as seas have in general a circular form, and are not distinguished from the largest craters except by their size. It is only

[1] "A Determination of the Polar Diameter of Mars." *A. J.*, No. 354, **15**, 145.

in exceptional cases that their surface exhibits the cones, eruptive funnels and rills that are found in such great numbers on the high plateaus. Their outline is often marked by a fissure, either single or double, which forms the boundary between the plain and the mountainous regions. Veins, standing in slight relief, are seen traversing the surface of the plain, having, like the fissures, a tendency to run concentrically with the rampart. (8) The seas have in general a dark color, like the plains inside the great craters. The color of the plateaus is lighter. A coating of special whiteness covers the central peak in many of the craters. (9) The surface of the Moon is strewn with a large number of white patches. In the majority of cases these patches surround craters of small or moderate dimensions, and if the central opening should appear to be wanting, it may be said, with a probability almost amounting to certainty, that a different illumination will reveal its existence. All the craters in the same region are often surrounded by these white aureoles. Specially to be noted among these objects are the curious streaks which radiate from a small number of craters, and extend to enormous distances. (10) The divergent streaks have no effect on the relief of the regions which they traverse. They cross the plains and the mountains without inflection, and show no tendency to flow down the valleys."

Several interpretations of these facts present themselves as possible. The following are regarded by the authors as the most satisfactory:

"The rills are, as we have already explained,[1] the traces of the imperfect joining of floating masses, having their origin in an early period when a solid crust was forming on the Moon's surface.

"The seas, and likewise the great craters, are the result of successive sinkings due to the action of forces having various origins.

"The polygonal form of the great craters was determined by the preëxistence of the straight rills, which in many cases constituted lines of least resistance and acted as limits to the final sinking of the crust.

"The same cause determined the grouping and alignment of the craters in certain directions. The projecting ramparts and the central mountains indicate that the subsidence was preceded by a general elevation of the region occupied by a crater, and by the formation of a volcanic cone near the summit of the protuberance. The elevated

[1] *C. R.*, **121**, 79–85, 1895.

veins which are found on the surface of the seas mark the course of ancient fissures filled by lava which solidified in obtrusion.

"The similar aspect of the seas and the flat interiors of the craters, the isolation or disappearance of the central peaks, indicate the partial invasion of the surface by lava which afterward solidified.

"The aureoles which surround the craters are deposited masses of volcanic cinders which were explosively projected. The divergent streaks resulted from the dispersion of these cinders to great distances under the action of variable atmospheric currents. The size and depth of the lunar craters have been regarded by various authors as irreconcilable with a volcanic hypothesis. There is, however, plenty of room for the belief that each great crater was not, as a whole, an eruptive opening, but that the space occupied by it was the theater of an intense volcanic activity, manifesting itself by a number of more or less large orifices. The testimony in favor of this view which is offered by all the facts relating to the aureoles and streaks seems to us absolutely decisive.

"The seas, more recently formed than the greater part of the craters, correspond to extensive sinkings of a crust already resistant, and capable of sustaining itself over a certain area. Their general arrangement reproduces with considerable fidelity that of the great depressions in the terrestrial crust, and notably that of the inland depressed areas which have been studied by geologists.

"The narrow fissures found to exist on the borders of the seas indicate concentric sinkings. Some of them appear to be rents in the soil caused by eruptive elevations."

Thus the authors have sought to refer all the characteristic and important features of the Moon's surface to a probable cause; and in doing so, they have found the basis for a chronological classification, which is given below.

"Taking as a point of departure the state of complete fluidity, we recognize as a well-marked first period that in which masses of scoria, agglomerated into fields of greater or less extent, appear upon the surface; these fields are often broken, and in cooling are subsequently reunited. The lines of junction and of rupture often remain, disposed according to a regular system which is clearly shown on our photographs.

"The formation of a continuous crust on the Moon marks the beginning of a second period, where the lava which accumulates at

certain points under the influence of the Earth's attraction or any other cause, no longer finds a free vent to the surface, and is obliged to create one. In an envelope still capable of offering moderate resistance, this tendency is revealed by the formation of cracks. The lava flows out by the way thus offered to the surface of the Moon. It soon solidifies, giving to the overflowed portions the aspect of a smooth plain.

"As time passes the crust becomes more solid; it opens only under the action of interior pressures powerful enough to raise it, by which swellings are produced, followed by depressions. This third period is that of the appearance of the great craters.

"At length elevations become exceptional and embrace areas more and more restricted. General sinkings, on the contrary, are still possible, and can extend over areas greater than the crust is capable of upholding without support. We are therefore led to distinguish a fourth period; that of a general sinking giving rise to the depressed areas known as seas.

"The existence of spots and streaks which cover indifferently the seas and the plateaus, the ramparts and the floors of the craters, incontestably proves the existence of a phase of activity more recent than the solidification of the surface of the seas. Hence there is room to consider a fifth period, in which, on account of the constantly increasing thickness of the crust, the most intense volcanic forces can only manifest themselves by temporary, though violent, eruptions, limited to orifices of small dimensions. These phenomena partly change the color of the surface without effacing the relief of its principal features.

"The white streaks issuing from definite centers radiate in all directions, and sometimes extend to enormous distances. Their recent origin is demonstrated by the fact that they leave absolutely intact the relief of the regions which they traverse, and their general appearance and character is evidence in favor of the former existence of a lunar atmosphere which it would seem difficult to confute."

Finally, the authors express the belief that it is not certain that the fifth period has entirely closed and that the era of absolute quiet has set in upon the Moon. The forms we see were probably produced when the thickness of the crust did not exceed ten or twelve kilometers —a thickness which is but a small fraction of the Moon's diameter. In the absence of all precise indications as to the age of these forma-

tions, we are permitted to regard general movements of the surface as still possible, and also such volcanic outbursts as have led to the formation of the great white streaks.

The selenographic theory here outlined resembles in many respects that of Suess, particularly in the important fundamental assumption of forces which are merely such as must have been active on the surface of the Earth, though modified in their action by the conditions peculiar to the Moon. There are, however, some important differences. According to Suess, the seas are "fusion hearths," formed by the remelting of the thin, partly solidified crust, and hence they represent one of the earliest stages in the formation of the surface; while their rocky walls are formed, not by a falling away of the crust on one side at an advanced stage of cooling, but by the pushing outward and crowding together of masses of slag at the rim of a great partially melted area. In the hypothesis of Loewy and Puiseux the formation of the seas is placed in the fourth period; in that of Suess, in what corresponds to their second.

The white rays or streaks have always been one of the chief selenographic puzzles, and every variety of explanation may be found in the great number of articles that have been written about them. The suggestion that they are volcanic ashes formerly ejected from craters has been previously advanced. Regarded in this aspect their most intractable feature is their straightness. Schaeberle supposed that they were straight and narrow for such great distances because there was no atmosphere to cause a deviation from the original plane of projection, but he was obliged to evoke the aid of an unknown extraneous force to account for their unsymmetrical distribution. According to W. H. Pickering, the rays are made up of smaller streaks, each of which proceeds from a minute crater. The component streaks are all tailed the same way, in consequence of atmospheric currents generated by eruption at or near the central crater, and condensation of the liberated vapors in a remote region. Suess regards the rays as due to bleaching of the surface rocks by acid vapors, which once escaped from orifices distributed along the line of original fissures. The late A. C. Ranyard thought they might be due to hoar frost, deposited from aqueous vapor escaping from such fissures as those just mentioned. These are a few examples of the more recent explanations.

If it is true, as some observers assert, that the eye can perceive with a small telescope details which cannot be photographed with a

very much larger one, the photograph must still be superior to eye observation for showing general features, and the relations between objects widely separated on the Moon's surface. If, further, there is any possibility (it would seem to be a small one) that volcanic force may again be called into play, the nature and extent of such changes in the surface as we may expect them to produce could be satisfactorily determined only by reference to photographs like those now being taken at Paris and Mt. Hamilton. But photographic maps of the Moon have been looked forward to so long, and have been discussed so often, that it is unnecessary to point out their various fields of usefulness. K.

Reviews.

Ueber Gesetzmässigkeiten in den Spectren festen Körper. F. Paschen. *Wied. Ann.* **58**, 455-492, 1896.

Under this well-chosen title, Dr. Paschen has not only furnished abundant experimental evidence for thinking that the radiation of energy from heated solids obeys laws, but he has also discussed his observations with consummate skill and has shown us just what some of these laws are.

The statement of the problem which Dr. Paschen has set before himself may, perhaps, be most simply made as follows. The spectrum of a gas, when produced by any of the ordinary electrical means, is said to be described when the wave-length and intensity of each line is given. Considerations of temperature enter, so also those of pressure, but at present the all important factors are the distribution of intensity in the line, and the wave-length (or frequency) of the maximum intensity. This information concerning spark or arc spectra is, in general, obtained partly by the eye, partly by the photographic plate, and partly by the bolometer. When, however, the spectrum of a solid body is under examination, whether it be considered as a limiting gaseous spectrum in which all wave-lengths are represented, or as a gaseous spectrum of one single line widened out so as to cover the whole range of wave-lengths, its description is complete, in either case, only when, for each particular wave-length, we know the intensity of the radiation and the temperature of the source. And, for measurable temperatures, the one available instrument is the bolometer or radiomicrometer.

The accurate experimental determination of this intensity as a function of temperature and wave-length in solid bodies, the accurate description of these results in a single mathematical expression, and the comparison of observations with mathematical predictions may be said to be the threefold object of the work under rewiew. Dr. Paschen's spectro-bolometer, with its fluorite prism, and his skill in the use of this difficult instrument, are too well known to need description in these colums. The solids to be heated were spread in layers

upon sheet-platinum. The platinum was heated by an electric current. The temperature of the source was thus under easy control, and was varied from 117° C. to 1001° C. Temperatures were measured by means of a well calibrated Pt—Pt.Rh. thermo-pile. The experimental part of the work (not to mention the extraordinarily large number of errors which must be either eliminated or allowed for in bolometric work), hinges on the determination of two sets of curves. One of these expresses the intensity as a function of the wave-length, while the temperature of the source remains constant. This is called the "energy curve." The other expresses the intensity as a function of the temperature, while the bolometric strip remains fixed at one wave-length. This is called the "isochromatic curve." For the energy curve, the temperature is the variable parameter; for the isochromatic curve, the wave-length is the variable parameter.

The report of this investigation is so free from the padding which sometimes permits a reviewer to condense results that any fair summary of Dr. Paschen's results calls for a complete translation. Among these results the following are some of the most important:

First.—If the energy curves are plotted, using as coördinates, *not* the intensity, J, and the wave-length λ, but $\log J$ and $\log \lambda$, it is found that these curves are congruent—have the same form—for all temperatures. This congruence, which was predicted by W. Wien, proves to be an exceedingly happy fact; for it enables one not only to fill out the absorption gaps which are introduced into the curve by the carbon dioxide and water vapor in the atmosphere, but also to complete the entire energy curve when once a few points on it have been measured, reminding one of the classical feat which the palæontologist performs with a few bones of an unknown skeleton.

The formulæ which H. F. Weber, W. Michelson, and Kövesligety have proposed as descriptions of the energy curve are disposed of, courteously but decisively, on the ground of incompetence; while Wien's expression for the intensity is practically identical with that at which Paschen arrives by experiment, viz.,

$$J = \frac{c_1}{\lambda^a} e^{-\frac{c_2}{\lambda T}}$$

where T denotes the absolute temperature, while c_1, c_2, and a are constants.

Second.—The wave-length of maximum intensity, λ_m in any energy curve, varies inversely as the first power of the absolute temperature for which the curve is plotted. This experimental result is also a mathematical inference from Wien's expression. It is found, however, that the following expression

$$\lambda_m \; T^{0.9500} = 1866.5$$

represents the observations (for iron oxide, at least) still better than the hyperbolic curve.

Third. So much for the *position* of the maximum intensity, λ_m If now we inquire concerning the *value* of the maximum intensity, J_m as dependent upon the temperature, the experimental result is summarized in the following equation:

$$J_m = C\,T^a$$

$$\text{where} \begin{cases} C = 3.519 \times 10^{16} \\ a = 5.6577 \end{cases}$$

This equation is to be carefully distinguished from the equation of energy curve. For iron oxide, then, the whole story is complete when the mean energy curve and the general values of λ_m and J_m (the two preceding equations) are given.

Fourth. The *total* radiation is roughly proportional to the fifth power of the temperature. More exactly

$$\int J\,d\lambda = c''\;T^{4.708}$$

where c'' is not a function of the temperature.

Fifth.—The isochromatic curves are plotted for iron oxide at six different wave-lengths; when logarithmic coördinates are used, these curves also are shown to be congruent. And this proves to be a fact of great utility; for knowing a few points on any isochromatic curve it is possible to complete this curve, and thus to determine the temperature at which the *energy* curve has its maximum at the particular wave-length which serves as a parameter for this isochromatic. Knowing the temperature of the maximum one can then, by the equation given above, viz.,

$$J_m = C\;T^{5.6577}$$

evaluate this intensity without having either to produce or to measure a temperature which may be inconveniently high for present laboratory methods.

If space were of no consideration, it would be interesting to follow a special method of plotting the isochromatic curves by which they are congruent with the energy curves. We must also forego a description of the method by which the radiation of the shutter is allowed for; likewise the manner in which one plots the intensity per unit difference of frequency as a function of the frequency. Dr. Paschen points out that what is true of iron oxide is also true of the other solids which he has examined, the only change in the general equation occurring in the constants. One is at a loss to know which to admire the more, the manipulative skill that furnishes normal spectra in the infra-red with a prism and bolometer, or the masterly discussion which gives such elegant graphical and algebraic expression to the results. In any case, one is forcibly reminded of Professor Karl Pearson's contention that the so-called "exact sciences" have forever disappeared and have been replaced by "descriptive sciences." And physics may be said to be a descriptive science *par excellence*, since it speaks a language which is terse and clear beyond the dreams of any rhetorician. The completion of Dr. Paschen's investigation will be awaited with unusual interest. H. C.

Experimental Determinations of the Temperature in Geissler Tubes. Phys. Rev., **4**, 191–206, and *Wied. Ann.*, **59**, 238–251, 1896.

When the history of the Geissler tube comes to be written, it is not unlikely that the last ten years of this century will stand out as an important period. For within this decade much definite information has been obtained, especially in the laboratories at Cambridge and Berlin, concerning the physical conditions under which electrical discharges occur in these tubes.

The investigation under review is an experimental determination of the local temperatures which prevail, inside the tube, during the passage of a constant current from a storage battery of 1250 volts. Incidentally Mr. Wood describes two neat experimental devices: one for using the Geissler tube as the bulb of an air thermometer, thus measuring the change in "average temperature" which results from the passage of the current; the other a delicate manometric tube for showing the extreme rapidity of the pressure variations (thermal changes) inside the tube when an intermittent current is employed.

The main part of the paper, however, is devoted to the investigation of the two following questions:

First.—At any one point in the tube, how does the temperature vary as a function of the current strength?

Second.—The current remaining constant, how does the temperature vary from point to point, as one passes from anode to cathode?

The first of these questions was answered by sealing a stationary bolometer in the tube and varying the current; while, for the second, Mr. Wood very ingeniously employed a Torricellian vacuum as a Geissler tube. This permitted him to use a movable bolometer arm carried on the upper end of a slender glass rod, running up through the mercury into the vacuum.

The chief results of the work are represented in several well chosen diagrams, which should be consulted by everyone interested. The most important of these results are two in number, viz.:

First.—The rise in temperature at any point in the tube, so far as can be detected by a bolometer wire $\frac{1}{30}$ mm in diameter, is trifling, not exceeding 30° C. when a current of 3 milliamperes is used.

Second.—The distribution of temperature along the tube is that which one would predict if all the heat developed were "Joule heat." This is the assumption of Warburg; and the assumption is justified by Mr. Wood's results.

Taking due account of the more or less rapid changes brought about by conduction and convection, the distribution in this gaseous conductor appears to be exactly that which is met in the case of a solid composite conductor conveying a constant current, viz., the heat is developed most rapidly in those parts in which the fall of potential is most rapid.

In all other sources of intense luminosity we are so accustomed to find high temperatures that one finds it difficult, in the absence of conclusive experimental evidence to the contrary, to believe that there is not, *somewhere*, in the Geissler tube also a source of high temperature. Mr. Wood has taken the precaution to use continuous currents. But to what degree are these currents really "continuous" in a medium which is continually "breaking down" under electrical stress? Is it not possible that here also the "streaks" which Wüllner observed with the rotating mirror may also occur?

On the other hand, it does not appear either impossible or improbable that the supposition of E. Wiedemann may be correct, viz., that

the electromotive forces brought to bear upon the tube may put into rapid vibration the ether associated with the molecules of matter (*Aetherhüllen*) without, at the same time, essentially altering the translational kinetic energy of the molecules. It will be remembered that Professor Michelson has offered independent experimental evidence for thinking that the temperatures of the Geissler tube are low (ASTROPHYSICAL JOURNAL, 2, 251, 1895).

These questions demand for their answer apparently a finer grade of machinery than that employed by Mr. Wood; albeit his measures are doubtless the best that have ever been made. In using a bolometer wire only $\frac{1}{30}^{mm}$ in diameter the limit of the method has perhaps been nearly reached; for even if the diameter of the wire were of molecular dimensions, and yet large enough to convey a bolometer current, it would seem highly probable that the rapid changes in temperature which might be indicated by it could no longer be followed by any instrument now available.

If, as a matter of fact, the temperatures indicated by Mr. Wood's bolometer strip approach asymptotically those indicated by an indefinitely small wire, and if the current is not in some way the *immediate* cause of light then the conditions of luminosity in the Geissler tube would appear to be, in many ways, analogous to those which Dr. Huggins has suggested for nebulæ. In his presidential address (*Brit. Assoc.* 1891) he says:

"On account of the large extent of the nebulæ, a comparatively small number of luminous molecules or atoms would probably be sufficient to make the nebulæ as bright as they appear to us. On such an assumption the average temperature may be low, but the individual particles, which by their encounter are luminous, must have motions corresponding to a very high temperature, and in this sense be extremely hot.

"In such diffuse masses, from the great mean length of free path, the encounters would be rare but correspondingly violent, and tend to bring about vibrations of comparatively short period, as appears to be the case if we may judge by the great relative brightness of the more refrangible lines of the nebular spectrum.

"Such a view may perhaps reconcile the high temperature which the nebular spectrum undoubtedly suggests with the much lower mean temperature of the gaseous mass, which we should expect at so early a stage of condensation, unless we assume a very enormous mass; or

that the matter coming together had previously considerable motion, or considerable molecular agitation."

It would appear in keeping with the simple physical properties which gases exhibit, in contrast with liquids and solids, that the Geissler tube, so far from maintaining its old position as a veritable *terra incognita*, should shortly become perhaps the best understood of all sources of light. H. C.

THE RADIATIONS OF URANIUM AND ITS SALTS.

Sur diverses propriétés des rayons uraniques. HENRI BECQUEREL *Comptes Rendus*, **122**, pp. 501, 559, 689, 762, 1086; **123**, 855. See also a review by G. Sagnac, *Jour. de Phys.*, 3d series, **5**, 193–202 1896.

IN the above papers is given an account of the properties of certain radiations of uranium, and the various uranium compounds. These radiations were discovered by Henri Becquerel, in the early part of 1896, and are most interesting because they seem to be intermediate between the ordinary ultra-violet radiations of the arc or spark discharge, and the X-rays discovered by Röntgen.

The properties of the uranium radiations are briefly these, as observed by Becquerel:

The radiations are emitted by all known salts of uranium, and best of all by the element itself, even if kept in a dark space for six and more months. The intensity of the radiation, as measured by its photographic action, decreases slightly in this interval. It acts upon both dry and wet photographic plates.

The radiation is hardly perceptibly increased by exposure of the substance to magnesium light, the radiation from a Crookes' tube, or to daylight, but an intense illumination may increase the radiation slightly. Crystals of uranium nitrate which have been formed in darkness have the same radiating power as crystals exposed to light.

The radiations pass through most bodies more easily than do the X-rays. This is specially true of the metals. Lead, however, is quite opaque, and tin, fairly so. Water and most solutions, even metallic, are transparent.

The radiations are not homogeneous, as is shown by the fact that the absorption by a superposition of screens of copper and aluminium

or of platinum and aluminium is less than the sum of the absorptions produced by each separately.

The radiation can be reflected and refracted, as is proved by direct reflection from a steel mirror or from a concave mirror of tin, and by refraction through a crown glass prism. Total reflection can also be observed. The effects, however, are so irregular that no measurements of the index of refraction can be made.

The radiation can also be polarized, as appears from the fact that two superimposed crossed tourmalines are much more opaque than two whose axis are parallel.

The radiation discharges bodies which are electrically charged if it falls upon them. This is proved by means of an electroscope. If the radiation passes through a gas (*e. g.*, air or Co_2), the gas will itself discharge the charged electroscope if it be blown against it, even if there is no direct action of the uranium on the instrument.

Care was taken in all the experiments to guard against the action of any uranium vapors, and the effects are found to depend largely on the amount of uranium present, quite independently of the elements with which it may be in composition.

As noted above, these uranium radiations have properties in common with both light and X-rays; and this fact serves to strengthen the belief that X-rays are transverse ether-waves of extraordinary shortness. J. S. AMES.

JOHNS HOPKINS UNIVERSITY,
December 1896.

1. *Anomalous Dispersion Curves of some Solid Dyes.* A. PFLÜGER. *Wied. Ann.*, **56**, 412–432, 1895.
2. *On the Indices of Refraction of Solid Fuchsin.* B. WALTER. *Wied. Ann.*, pp. 394–396, 1896.
3. *On the Anomalous Dispersion of Absorbing Substances.* A. PFLÜGER. *Wied. Ann.*, **58**, 670–672, 1896.
4. *On the Indices of Refraction of Metals at Different Temperatures.* A. PFLÜGER. *Wied. Ann.*, **58**, 493–499, 1896.

DISPERSION curves of some of the strongly absorbent dyes had been given by Pulfrich, Ketteler and others, using alcoholic solutions, and E. Wiedemann, Lundquist and Merkel had given similar curves

for solid dyes obtained from measurements of elliptic polarization: the difficulty of interpreting the former results, and discrepancies among the latter, together with possible uncertainties in their theoretical deduction, led Pflüger to make the observations given in this first paper. He used solid prisms of very small angle ($40''$ to $140''$) and a method substantially that which Kundt used in his work on the indices of refraction of the metals. Wernicke had previously used solid prisms of fuchsin, but of such large dimensions that no observations could be made inside the absorption bands. By using prisms of the very small angle above given Pflüger is able to observe the dispersion curve continuously from $\lambda = 6710$ to $\lambda = 4100$, though the image of his slit inside the strongly absorbent bands is, as would be expected, by no means sharp. That the great variation in the absorption from the thin to the thick side of his prism did not introduce any noticeable systematic error in his results seems to follow, as in Kundt's case, from the fact that he used prisms of varying angle, and found no systematic variation of the indices with the angle.

The substances examined were: fuchsin, cyanin, Hoffman's violet, magdaleroth, malachitegrün; and the most interesting results are: (1) inside the absorption bands the index of refraction decreases with decreasing wave-lengths; (2) fuchsin and Hoffman's violet gave values of the index less than unity, at the short wave-length end of their absorption bands; (3) inside the absorption bands the index varies with the angle of incidence (or, Snell's law does not hold).

The article of Walter gives a tabular comparison of indices of refraction of solid fuchsin for certain strongly absorbed wave-lengths, calculated on the one hand, from indirect observations before mentioned, by E. Wiedemann, Glan and others, and Walter, with those given by Pflüger in the preceding article. Walter calculated his values by means of Cauchy's theory from his observations of elliptic polarization, and there is a very close agreement between them and those of Pflüger, and very wide discrepancies between these and the others. In Pflüger's second paper he makes a similar comparison between his results and Walter's for "diamantgrün;" the agreement is again quite good inside the absorption bands, and poor outside. Walter's values for the weakly absorbed wave-lengths were obtained from total-reflection measurements, and why they should in both cases differ so widely from Pflüger's is not clear. Pflüger also calls attention to the values of indices less than and equal to unity, above mentioned: these and

similar results of Kundt's for some metals are of interest in connection with the view that the Röntgen rays are transverse ether vibrations of very short period for which all substances examined have indices equal to unity.

The fact that a number of the metals arrange themselves with respect to their indices of refraction in the same order as with respect to their electrical and thermal conductivities, led Kundt to an investigation of the temperature variation of these indices, to see if the same similarity held there. He found that the temperature coefficients of the indices were of about the same absolute magnitude but of opposite signs to the temperature coefficients of the conductivities. His results were not verified by later observers, notably Drude and Zeeman; Pflüger has therefore repeated Kundt's observations with greater care and he finds no measurable temperature variation of the indices of Ni, Au, and Fe. C. E. MENDENHALL.

On a New Photographic Method of Photometry and its Use in the Ultra-Violet. H. TH. SIMON. *Wied. Ann.*, **59**, 91–115, 1896.

THE photometric method of Simon may be briefly outlined as follows: Two portions of a photographic plate are simultaneously exposed in exactly similar ways to light from two sources — the one the standard source, the other the light to be compared. The latter is then gradually weakened, and the plate at the same time uniformly moved so as to expose a new portion of its surface. Upon development that part of the plate exposed to the standard source will be uniformly darkened throughout its whole whole length, while the other portion will gradually diminish in density. At a certain point of the length the two halves will be of equal density; by knowing the extent to which the strong light has been weakened at this instant, its value in terms of the standard is directly obtainable. Of course this method is only applicable to the comparison of homogeneous lights of the same wavelength. The apparatus as devised and used by Simon consists of the following parts: (1) a spectrometer, having a quartz train, and in place of the eyepiece, a second slit and a device for moving the photographic plate past this slit. (2) The light-weakening apparatus, for which purpose the ordinary sectored disk is used, but so arranged that the apertures of the disk (of which there are three, of 60° each) can be gradually closed by a second disk and this while the two disks are

rapidly rotating. (3) Connecting mechanism by means of which any given angular opening of the apertures of the disk is made to correspond to a definite position of the sensitive plate. The plates so exposed and developed have a dark line separating the two halves which are to be compared, and in order to avoid the difficulties of comparison which this introduces a special comparison device is used. This consists of an objective, bi-prism, and eyepiece, and has its objective end covered with a diaphragm containing two semi-circular apertures; it is so adjusted that one of the images, formed by the bi-prism, of aperture *a* is brought accurately opposite and in contact with an image of *b*. The two halves of the developed plate being placed in front of *a* and *b*, respectively, and moved along, the position of equal density can be found to within about $0^{mm}.6$. It is seen that this method assumes that the photographic action is the same for a given light time of exposure, whether that exposure is continuous or intermittent; previous observers have differed on this point — and it is probably not true at the limit of sensibility of a plate; but Simon seems to have justified the assumption for the conditions under which he worked, by comparing disks having the same total aperture, but having individual apertures of greatly different sizes. Under ordinary conditions the method is accurate to about 0.5 or 0.6 per cent. The method is also applicable to the measurement of absorption coefficients, and has been applied with quite satisfactory results to one case, which is given in the original paper, together with full details of adjustment.

C. E. MENDENHALL.

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HARZER, P. Ueber die Rotationsbewegung der Sonne. A. N. **142**, 23–25, 1896.

LEWITZKY, G. Sonnenfleckenzählungen (Dorpat). A. N. **142**, 7–9, 1896.

WILSING, J. Bericht über Versuche zum Nachweis einer elektrodynamischer Sonnenstrahlung von J. Wilsing und J. Scheiner. A. N. **142**, 17–22, 1896.

3. STARS AND STELLAR PHOTOMETRY.

ANDERSON, T. D. New Variable Star in Hercules. A. N. **141**, 419, 1896.

CHANDLER, S. C. Ephemeris of Long-Period Variables for 1897. Ast. Jour. No. 387, **17**, 17–20, 1896.

HOLDEN, E. S. Beobachtung des Siriusbegleiters. A. N. **142**, 13, 1896.

NYLAND, A. Beobachtungen von Mira Ceti. A. N. **141**, 419, 1896.

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PICKERING, E. C. A new spectroscopic binary, μ^1 Scorpii. A. N. **142**, 11–13, 1896.

5. Planets, Satellites and their Spectra.

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Childs, H. Y. Observations of a Dark Spot in Jupiter's N. Hemisphere. Obs'y **19**, 403–404, 1896.

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Hussey, W. J. Projection on the Terminator of Mars. A. N. **141**, 403, 1896.

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Lynn, W. T. Ga[illegible]'s Observations of Saturn. Obs'y **19**, 400–401, 1896.

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6. Comets, Meteors and their Spectra.

Callandreau, O. Sur la désagrégation des comètes. C. R. **123**, 663–664, 1896.

Stoney, G. J. The Leonids. Obs'y **19**, 387–391, 1896.

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Bose, J. C. On the determination of the wave-length of electric radiation by a diffraction grating. Proc. R. S. **60**, 167–178, 1896.

Ramsay, W., and Collie, J. N. The Homogeneity of Helium and Argon. Proc. R. S. **60**, 206–216, 1896.

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10. THE SPECTRA OF THE ELEMENTS.

HARTLEY, W. N. On the spectrum of Cyanogen as produced and modified by spark discharges. Proc. R. S. **60**, 216–221, 1896.

11. PHOTOGRAPHY.

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13. GENERAL ARTICLES.

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The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

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THE

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THE ABSORPTION OF LIGHT AS A DETERMINING FACTOR IN THE SELECTION OF THE SIZE OF THE OBJECTIVE FOR THE GREAT REFRACTOR OF THE POTSDAM OBSERVATORY.[1]

By H. C. Vogel.

The extraordinary advances which technical science has recently made in the manufacture of glass for optical instruments, and especially for telescope objectives, extend not only to the production of very large and pure pieces for the latter purpose, but to the production of highly refrangible glass as free as possible from color.

At the technical laboratory at Jena varieties of glass have also been made, by the combination of which the secondary spectrum has been reduced to an almost imperceptible quantity, so that achromatic objectives of almost ideal perfection have actually been made and have come into use; but although the efforts which only two decades ago appeared to be hopeless—to produce kinds of glass which could be so combined—have thus been crowned with success, it was only too soon apparent that the kinds of glass used were not permanent when exposed to the air, as they soon became covered with an opaque film

[1] "Die Lichtabsorption als maasgebender Factor bei der Wahl der Dimension des Objectivs für den grossen Refractor des Potsdamer Observatoriums," *Sitz. d. K. Akad. d. W. Berlin* 46, 1219–1231, 1896.

which made the objective unserviceable. At present, therefore, progress in the direction of object glasses for large telescopes has extended only so far as this, that glass of admirable purity and of almost complete freedom from color is available for their manufacture.

Lenses as free as possible from color are especially desirable when the telescope is to be used, not only for direct observations, in which case the less refrangible rays are those chiefly concerned, but also for photographic purposes. For the otherwise excellent, but strongly yellow glass used by Fraunhofer, the limit, up to which an increase of the diameter of a photographic objective is profitable (a consequence of the increased absorption as the thickness is increased), is reached at a diameter of about 35^{cm} to 40^{cm}; whereas, in the case of the more recent kinds of glass, this limit is approached only at a diameter about three times as great.

Various factors existed for determining the construction of the large refractor designed for the Potsdam Observatory and for fixing the size of the objective. Although the situation of the Observatory, so far as the atmosphere is concerned, may be regarded as a favorable one for Central Germany, it nevertheless cannot be compared with that of observatories located at greater elevations, as, for instance, the observatory on Mount Hamilton. A telescope with a visually achromatized objective of a size similar to that of the later American instruments could be but seldom used to advantage under the atmospheric conditions met with here, and only in exceptional cases could it furnish observations which would have equal weight with those of other and more advantageously located observatories. Aside from this, the chief purpose of the Observatory, in accordance with which its activities are restricted as closely as possible to the domain of astrophysics, was to be kept in view; especially to be considered was the construction of an instrument by means of which it would be possible to continue the investigation of the motions of the heavenly bodies in the line of sight — an investigation in which this Observatory took the first successful steps, and the methods

for observing which it has established. A favorable condition of the atmosphere, however, has not so important an influence on spectrographic as it has in general upon visual observations.

In the case of the recent large telescopes, for instance that of the observatory at Pulkowa and that of the Lick Observatory, the objectives of which are achromatized for the visual rays, the imperfect achromatism of the objective becomes disagreeably evident in spectroscopic investigations not limited to the visible part of the spectrum, inasmuch as only a small part of the more refrangible regions of the spectrum can be investigated at a time. The extent of the part which can be so investigated decreases as the dimensions of the instrument, and the separation of the focal points of the actinic rays, thereby determined, increase. I here briefly give a few figures taken from a previous investigation[1] of mine concerning the achromatism of the Potsdam refractor of $29^{cm}.8$ effective aperture, and of the Vienna refractor of $67^{cm}.5$ effective aperture,[2] in order that the reader may recall the magnitudes of the quantities here considered:

Potsdam Refractor		Vienna Refractor	
Wave-length $\mu\mu$	Distance of the focal point from λ 486 $\mu\mu$	Wave-length $\mu\mu$	Distance of the focal point from λ 486 $\mu\mu$
690	$+ 4^{mm}.2$	690	$+ 2^{mm}.1$
610	$- 0\ .3$	610	$- 6\ .7$
530	$- 1\ .7$	570	$- 7\ .8$
470	$+ 1\ .6$	470	$+ 4\ .4$
430	$+ 9\ .2$	430	$+ 20\ .7$
410	$+ 16\ .7$	410	$+ 31\ .1$

Attempts to unite more accurately the actinic with the optical rays by inserting a correcting lens in the cone of light have, so far as my knowledge goes, led to no satisfactory results.

These experiences led quite naturally to the conclusion that the objective of the great refractor should be achromatized for the actinic rays. An advantage in the mechanical construction

[1] *Monatsber. d. K. Akad. d. W. Berlin*, 1880, p. 438.

[2] *Publ. d. Astrophys. Obs. zu Potsdam*, IV Bd., I Th., p. 54.

of the instrument and the dome was gained at the same time: that of obtaining with the same aperture a large reduction in the focal length of the objective and also a large reduction in the diameter of the dome. There existed, however, the necessity for providing the large instrument with a guiding telescope of the same focal length.

The intention at first was to devise an attachment for the large telescope (a system of lenses), by means of which a more complete union of the visual and actinic rays might be effected, and which might be thrown in or out at pleasure. However, since such a system, in order to be effective, would have to be composed of three lenses, and these, in order to obtain a fairly large field of view, could not be given a smaller diameter than 30^{cm} to 40^{cm}, various doubts arose as to the feasibility of the plan, having their origin partly in the not inconsiderable cost of the mechanical arrangement, as well as that of the lenses themselves. It was therefore decided to correct the large objective (achromatized for the chemically active rays) merely by means of a small double lens of Christie's construction, which should be introduced at a short distance from the focus when the large objective was required for spectroscopic investigations in the less refrangible parts of the spectrum, thus relinquishing any attempts to secure a considerable field of view. An experiment with such a correcting lens, which Steinheil of Munich computed and made for the photographically corrected refractor of 34^{cm} aperture and $3^{m}.4$ focal length, resulted quite satisfactorily.

Since for these reasons the great objective can be used to only a very limited extent for direct observation, the aperture of the guiding telescope was fixed at 50^{cm}, so that the guiding telescope itself must be regarded as a very effective instrument of observation; in fact, it exceeds in size all previously existing instruments in Germany.

In order to determine the size of the principal objective, a complete knowledge of the absorption of the kinds of glass to be used was especially necessary, since, as is well known, the absorption of the more refrangible rays, for which the objective

was to be achromatized, is greater than that of the less refrangible. The kinds of glass were, in accordance with the suggestion of Steinheil, who undertook the construction of the objective, ordinary light flint, O.340 (catalogue number of the technical laboratory at Jena), and ordinary silicate crown O.203, since these kinds of glass are easily obtained in large disks free from defects. No quantitative results as to the amount of absorption of these kinds of glass were at hand, and preliminary investigations were consequently undertaken at the Potsdam Observatory, with the result that 80^{cm} was adopted as the size of the objective. It is, therefore, larger than the objective of the Pulkowa Observatory, and will be the largest in Europe.

The great refractor of the Potsdam Observatory will accordingly consist of a double telescope, one tube having an objective of 80^{cm} aperture, achromatized for actinic rays, the other having an aperture of 50^{cm}, achromatized for visual rays. The focal lengths will be respectively 12^{m} and $12^{m}.5$, so that the ratio of the aperture to the focal length will be 1 : 15 for the principal instrument and 1 : 25 for the guiding telescope.

The investigations of the absorption of the kinds of glass decided upon for the objective were conducted chiefly by Professors Müller and Wilsing at this Observatory, and were concluded during the summer. Advantage was also taken of the opportunity to observe the effects of absorption of other kinds of glass, which are to be used for the spectrograph of the great refractor. Inasmuch as there are very few such determinations for new kinds of glass,[1] I believe that the publication of the following observations will be of somewhat wide interest, and that comparisons of different objectives given at the conclusion of this article will correct some erroneous notions which are frequently met with concerning the influence of absorption.

[1] I would here refer to: Conroy, "Some observations on the amount of the light reflected and transmitted by certain kinds of glass," *Phil. Trans.*, 180, 245, 1889. Dr. Krüss, "Über den Lichtverlust in sogenannten durchsichtigen Körpern," *Abh. d. Naturwissensch. Vereins zu Hamburg*, Bd. XI, Hft. 1. Eder and Valenta, "Absorptionspectren von farblosen und gefärbten gläsern," *Denkschr. d. K. Akad. d. W. Wien*, Bd. LXI, 1894.

I. DETERMINATION OF THE ABSORPTION IN THE VISIBLE PART OF THE SPECTRUM BETWEEN $\lambda 677^{\mu\mu}$ AND $\lambda 436^{\mu\mu}$.

The following observations were conducted by Professor Müller, with a Glan's spectrophotometer[1] somewhat modified by myself. It need scarcely be mentioned that every precautionary measure was taken in the investigations, and that only a cylindrical beam, and no diffuse light, was sent through the glass plates. The figures (the mean of four settings) give the intensity of the light, after passing through the glass, in terms of the incident light. The computation of the effect of reflection was made for each kind of glass by means of Fresnel's formula, $I = 1 - \left(\frac{n-1}{n+1}\right)^2$, where n is the index of refraction. It was sufficient for the purpose to take for the index of refraction that of the mean wave-length of the part of the spectrum investigated, and n for b_1 ($\lambda 518^{\mu\mu}$) was therefore taken. The effect of multiple reflections within the parallel plane surfaces of the glass has been neglected as insignificant. The reduction of the absorption to a thickness of the glass $a = 100^{mm}$ is obtained from the formula, $I_1 = I_0\ K^{\frac{a}{\beta}}$, in which K is the quantity of light after having passed through the absorbing medium of thickness β, in terms of the incident light.

Flint glass O.340
Thickness = 148^{mm}
n for b_1 1.5835

λ	Measurements				Without reflection	For thickness of glass 100^{mm}
	Series I	Series II	Series III	Mean		
677	0.744	0.858	0.862	0.821	0.912	0.939
580	0.719	0.783	0.726	0.743	0.825	0.878
535	0.667	0.880	0.793	0.780	0.866	0.907
503	0.804	0.735	0.697	0.745	0.827	0.880
477	0.819	0.715	0.705	0.746	0.828	0.880
455	0.652	0.705	0.711	0.689	0.765	0.834
436	0.492	0.493	0.542	0.509	0.565	0.680

[1] *Monatsber d. Akad.*, Marz 1877.

Flint glass O.102
Thickness = 100^{mm}
n for b_1 = 1.657

λ	Measurements			Without reflection	For thickness of glass = 100^{mm}
	Series I	Series II	Mean		
677	0.695	0 704	0.700	0.794	0.794
580	0.718	0.745	0.731	0.829	0.829
535	0.720	0.704	0.712	0.808	0.808
503	0.688	0.689	0.689	0.782	0.782
477	0.603	0.632	0.617	0.700	0.700
455	0.615	0.553	0.584	0.663	0.663
436	0.544	0.453	0.499	0.566	0.566

Flint glass O.93
Thickness = 114.8^{mm}
n for b_1 = 1.632

λ	Measurements					Without reflection	For thickness of glass = 100^{mm}
	Series I	Series II	Series III	Series IV	Mean		
677	0.878	0.771	0.910	0.763	0.830	0.935	0.943
580	0.777	0.818	0.824	0.741	0.790	0.890	0.903
535	0.699	0.777	0.743	0 844	0.766	0.863	0.879
503	0.818	0.693	0.736	0.786	0.758	0.854	0.871
477	0.724	c.824	0.744	0.852	0.786	0.885	0.899
455	0.707	0.737	0.669	0 668	0.695	0.783	0.807
436	0.584	0.551	0.564	0.713	0.603	0.679	0.714

Crown glass O.203
Thickness = 141.5^{mm}
n for b_1 = 1.521

λ	Measurements			Without reflection	For thickness of glass = 100^{mm}
	Series I	Series II	Mean		
677	0.848	0.738	0.793	0.865	0.903
580	0.730	0.778	0.754	0.823	0.872
535	0 770	0.804	0.787	0.859	0.898
503	0.784	0.723	0.754	0.823	0.872
477	0.706	0.773	0.740	0.807	0.860
445	0.666	0.723	0.695	0.758	0.822
436	0.701	0.650	0.676	0.738	0.806

Crown glass O.598
Thickness = 102^{mm}.5
n for b_1 = 1.519

λ	Measurements			Without reflection	For thickness of glass = 100 mm
	Series I	Series II	Mean		
677	0.824	0.747	0.786	0.857	0.860
580	0.768	0.723	0.746	0.814	0.818
535	0.810	0.634	0.722	0.787	0.792
503	0.720	0.694	0.707	0.771	0.776
477	0.701	0.704	0.702	0.766	0.771
455	0.721	0.681	0.701	0.765	0.770
436	0.832	0.623	0.727	0.793	0.797

Observations in the blue at λ 436$^{\mu\mu}$ were difficult with petroleum light on account of the feeble intensity of this part of the spectrum, and since my eye is very sensitive to the more refrangible rays of the spectrum, I have repeated these observations, and at the same time have also made a few observations in the brightest part of the spectrum. I give here the values obtained, which agree very well with those found by Professor Müller.

Flint glass O.340

λ	Measurements				Without reflection	For thickness of glass = 100mm
	Series I	Series II	Series III	Mean		
580 } 535 }	0.770	0.708	....	0.739	0.821	0.875
436	0.567	0.494	0.552	0.538	0.597	0.706

Flint glass O.102

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
580 } 535 }	0.669	....	0.669	0.759	0.759
436	0.470	0.485	0.478	0.542	0.542

Common glass O.203

λ	Measurements			Without reflection	For thickness of glass = 100^{mm}
	Series I	Series II	Mean		
580 } 535 }	0.734	....	0.734	0.801	0.855
436	0.648	0.606	0.627	0.684	0.765

Common glass O.598

λ	Measurements			Without reflection	For thickness of glass = 100^{mm}
	Series I	Series II	Mean		
580 } 535 }	0.741	....	0.741	0.808	0.812
436	0.593	0.595	0.594	0.648	0.655

2. DETERMINATION OF THE ABSORPTION OF THE MORE REFRANGIBLE RAYS BETWEEN λ $434^{\mu\mu}$ AND λ $375^{\mu\mu}$.

Before entering upon the more special parts of the investigation I must state, with reference to the properties of glass in general, that the absorbing power does not increase uniformly with the decrease in the wave-length; that rather an approximately constant effect is to be observed over large sections of the spectrum, and that the increase of the absorption takes place *per saltum*, as in the vicinity of the Fraunhofer lines G and H. The sudden and total disappearance of light of a certain wave-length with a certain thickness of glass is thus explained. For example, light flint glass of 10^{cm} to 15^{cm} thickness cuts off all light whose wave-length is less than $376^{\mu\mu}$. In the case of heavy flint O.102 a sudden and very marked decrease in the intensity of the transmitted light may be observed in the neighborhood of H. The spectrum may be followed a short distance beyond K, but it is excessively weak, and is then once more suddenly broken off. These observations agree with those of Eder and

Valenta,[1] who, with a thickness of glass of only 1^{cm} have been able to observe a similar, quite sudden falling off in intensity with most of the glasses investigated by them. Corresponding to the smaller thickness of glass, a total extinction of light did not occur until the point $\lambda\ 330^{\mu\mu}$ was reached.

It further appeared that flint O.340 of about 15^{cm} thickness produced two absorption bands. The middle of the one, a very weak and diffuse band, has a wave-length of $437^{\mu\mu}$, the middle of the other, a more sharply defined and quite conspicuous band, has a wave-length of $418^{\mu\mu}.6$. The width of the latter corresponds to a difference of wave-length equal to $3^{\mu\mu}.5$. The second absorption band also appeared in the spectrum when the light was passed through a plate of crown glass O.203 of about 14^{cm} thickness, but it appeared to be less strong. The heavy flint O.102 gave no absorption bands.

The determination of the absorption for certain places in the more refrangible parts of the spectrum by means of photography was beset by great difficulties arising from the fact that, according to recent investigations in photographic processes where the darkening of the plate is produced, not by the light directly, but by a process of development, a great difference exists between the resulting degrees of darkening and the product of the time and intensity concerned in their production. With the same exposure the photographic darkening does not increase proportionally to the intensity, but more slowly, and the deviation from such a law is different for plates of different manufacture. In order to deduce the intensity from equal darkenings, the times of exposure being known, the departure from the law, $It = C$, must be especially obtained for each plate, which in practice leads to difficulties scarcely to be surmounted.

Professor Wilsing has attempted to overcome this difficulty by limiting himself to the comparison of intensities differing but little from one another with equal times of exposure, so

[1] "Absorptionsspectren von farblosen und gefarbten Glasern," *Denkschr. d. K. Akad. d. W. Wien*, Bd. LXI, 1894.

that the measurements are based on the axiom that equal intensities produce in the same time equal darkenings. By measurements with Nicol prisms the reduction of two intensities, differing by any desired amount, to the same intensity, was made in accordance with the principle of Zöllner's photometer, and the photometric determinations in the more refrangible part of the spectrum differ, therefore, from those made by spectrophotometric means in the less refrangible part, in this respect only,—that the plate sensitive to light takes the place of the eye.

A more detailed presentation of the method pursued and the precautionary measures taken in carrying out the observations will be given by Professor Wilsing in the *Astronomische Nachrichten*. I here limit myself to pointing out their principal features, merely adding thereto the remark, with reference to the practical carrying out of the work, that the photographs were taken on bromide of silver gelatine plates with a small spectrograph which is frequently used, in combination with the photographic refractor of the Observatory, for photographing star spectra. It was found that a difference of 5 per cent. in the intensity could be recognized.

The results of measurements given in the following table are arranged and reduced in the same way as those given on pages 80 and 81. For computing the loss by reflection the index for h (λ 410$^{\mu\mu}$) was taken.

Flint glass O.340
Thickness = 148^{mm}
n for h = 1.601

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.389	0.434	0.569
(419)	(0.240)	(0.268)	(0.411)
400	0.435	0.486	0.614
390	0.280	0.313	0.456
375	0.221	0.247	0.388

The figures enclosed in brackets refer to the absorption band.

Flint glass O.102
Thickness = 100^{mm}
n for h = 1.682

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.439	0.502	0.502
400	0.405	0.463	0.463
395	0.146	0.167	0.167
390	0.022	0.025	0.025

Crown O.203
Thickness = 141^{mm}.5
n for h = 1.532

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.515	0.564	0.667
(419)	(0.455)	(0.498)	(0.611)
400	0.546	0.598	0.695
390	0.426	0.466	0.583
375	0.426	0.466	0.583

The figures enclosed in brackets refer to the absorption bands.

I have attempted to determine the absorption effect of the glass for the more refrangible rays in another way,—by exposing sensitive paper (chloride of silver) to the sunlight both directly and after it had passed through the glass to be investigated, and then determining the degree of darkening by means of a scale which was produced by successive exposures to light. The comparison was made in yellow light, since it was not permissible to fix and tone the papers. Bunsen and Roscoe[1] have shown that, within very wide limits, equal products of intensity of light and time of exposure represent equal darkenings of chloride of silver paper. I had formerly used the method to advantage in determining the diminution of light from the center to the limb of the Sun's disk,[2] and I have now

[1] *Pogg. Ann.*, 117, 529 *et seq.*

[2] *Berichte d. K. d. W.*, Leipzig, July 1872.

verified my conclusion that by making a suitable choice of the time of exposure it was possible to attain a quite high degree of sensitiveness and to recognize a difference of intensity as small as 5 per cent.

From a large number of observations, in which not only the absorbing effect of each of the glasses separately was determined, but also the absorption of the different glasses relatively to one another, I have deduced the following results, which relate to rays that affect chloride of silver paper, *i. e.*, rays of the spectrum extending from G into the ultra-violet and having a maximum effect between *h* and H.

Kinds of glass	d	I_1	I_2	I_2 for d = 100mm
Flint O.340	148.0	0.346	0.386	0.526
Flint O.102	100.0	0.247	0.282	0.282
Flint O.93	114.8	0.270	0.306	0.356
Crown O.203	141.5	0.432	0.473	0.589
Crown O.598	102.5	0.547	0.610	0.604

Here d is the thickness of the glass in millimeters, I_1 the intensity, in terms of the incident light, of the light after having passed through a thickness of the glass plate equal to d, I_2 the intensity after allowing for the loss due to reflection, for the calculation of which, instead of the values for n which have been given, 1.654 is taken for Flint O.93 and 1.529 for Crown O.598.

In order to form an idea of the difference between the absorbing effect of the glass in visual observations and in photography, the preceding determinations of the absorption for certain definite kinds of rays must be combined, with reference to the power of the corresponding rays to affect respectively the eye and the photographic plate. For the less refrangible rays, which are chiefly concerned in direct observations, the mean may at once be taken of Professor Müller's observations combined with my own; since most of the observations are in the brightest part of the spectrum, and by forming the mean the distribution of light with reference to intensity is

sufficiently taken into account. For the two kinds of glass which are to be used for the objective, the following values were obtained for the intensity of the light after having passed through a thickness of 100^{mm}, in terms of the incident light:

0.84 for Flint O.340 and
0.85 for Crown O.203

In determining the absorption for the photographic rays I have assumed that the widespread bromide of silver gelatine plates are used. Their sensitiveness begins at F and extends far into the ultra-violet, and has a maximum between H_γ and H_δ. I take from the preceding investigations the following values from which to obtain a mean:

λ	Flint O.340	Crown O.203
$455^{\mu\mu}$	0.83	0.82
436	0.69	0.79
434	0.57	0.67
400	0.61	0.70
h — H	0.53	0.59
390	0.46	0.58
	Mean 0.615	Mean 0.692

Since the kinds of glass intended for the objectives of the Potsdam refractor are those which are generally preferred for large instruments, and the glass of the laboratory at Jena is coming into more extended use, the following table, which was computed on the basis of the values deduced above, will be of practical importance:

Thickness of objective in cm	Intensity of the transmitted in terms of the incident light			
	With allowance for absorption only		With allowance for absorption and reflection	
	Visual rays	Actinic rays	Visual rays	Actinic rays
4	0.93	0.84	0.77	0.69
6	0.90	0.77	0.75	0.63
8	0.87	0.71	0.72	0.58
10	0.84	0.65	0.70	0.53
12	0.82	0.60	0.67	0.49
14	0.79	0.55	0.65	0.45
16	0.76	0.50	0.63	0.41
18	0.74	0.46	0.61	0.38
20	0.71	0.43	0.59	0.35
22	0.69	0.39	0.57	0.32
24	0.67	0.36	0.55	0.29
26	0.65	0.33	0.53	0.27
28	0.62	0.30	0.52	0.25
30	0.60	0.28	0.50	0.23
32	0.58	0.25	0.48	0.21
34	0.56	0 23	0.47	0.19
36	0.55	0.21	0.45	0.18
38	0.53	0.20	0.44	0.16
40	0.51	0.18	0.42	0.15

The total thickness of the objective may, for the purpose of calculation, be taken at one-sixth or one-seventh of the diameter.

From the preceding table it follows that for the large objective of the new Potsdam refractor of 80^{cm} aperture, and of an assumed thickness of 12^{cm}, the loss of the actinic rays by absorption is approximately 40 per cent.; by both absorption and reflection 51 per cent. The ratio of the intensity of the transmitted light to that of the incident is 49 : 100.

To compare this with the objective of the Institute's photographic refractor of $34^{cm}.4$ aperture and 5^{cm} thickness, the ratio of the light-gathering power of the objectives is computed by multiplying the ratio of the squares of their apertures by the ratio of the amounts of transmitted light, expressed in terms of the same unit; that is $\frac{(80)^2}{(34.4)^2} \cdot \frac{49}{66} = 4$. The images of stars at the focus are therefore four times as bright for the

objective of 80^{cm} diameter as for the objective $34^{cm}.4$ in diameter, which corresponds to a gain of 1.5 stellar magnitude. A comparison with the Schröder refractor of the Observatory of $29^{cm}.8$ aperture, with which the determination of the motion of stars in the line of sight down to a magnitude of 2.5 was made, gives a much more favorable result. It may be assumed that with the objective of 80^{cm} aperture at least two additional magnitudes will be added to the range of observation. The number of stars whose motion can be investigated with the same precision as heretofore will be increased eightfold, or to about 400.

In spectroscopic investigations in the less refrangible part of the spectrum the intervention of a correcting lens becomes necessary, and this involves a still greater loss of light which can, however, scarcely be estimated at more than 20 per cent., since the compound lens will at most be about 20^{cm} in diameter and 4^{cm} thick, and the component lenses can be cemented together. Nevertheless, in consequence of the much smaller absorption for the optical rays, the gain of light of the large objective in comparison with that of the Schröder refractor will still be 1.8 magnitudes.

I may here also make a comparison in another direction, and will answer the question, "What advantage would be obtained by the use of a still larger objective, for instance one of 100^{cm} aperture?" If the thickness of the objective be taken as 15^{cm}, the result for the chemical rays is $\frac{100^2}{80^2} \cdot \frac{43}{49} = 1.43$, corresponding to a gain of 0.3 to 0.4 magnitude; a gain which is disproportionate to the very heavy cost of the objective and mountings.

Finally, I may give a comparison of the photographic refractor of $34^{cm}.4$ aperture, for which the ratio of aperture to focal length $= 1:10$, with the large objective of 80^{cm} aperture, with respect to the images which they form of objects that are not points. Here the ratio of aperture to focal length is chiefly concerned. Let V be this ratio, and let quantities relating to the large objective be represented by capitals, and those of

the small objective by small letters of the alphabet. Then

$$\frac{h}{H} = \frac{i}{I}\left(\frac{v}{V}\right)^2,$$

where I is the intensity of the transmitted light in terms of the same unit. The result is

$$\frac{h}{H} = \frac{66}{49} \cdot 1.5^2 = 3.$$

The brightness of the image per unit of surface for the smaller objective with relatively short focal length is therefore three times as great as for the large objective. The images in the focal plane of the latter have, however, twelve and one-half times as large an area.

THE SPECTRUM OF ζ PUPPIS.

By Edward C. Pickering.

The announcement was made in *Circular* No. 12 that the spectrum of the star ζ Puppis contained, in addition to the usual series of lines due to hydrogen, a second series of rhythmical lines. A remarkable relation exists between these two series, from which it appears that the second series, instead of being due to some unknown element as was at first supposed, is so closely allied to the hydrogen series, that it is probably due to that substance under conditions of temperature or pressure as yet unknown. The wave-lengths of the lines of hydrogen may be computed by the formula $\lambda = 3646.1 \frac{n^2}{n^2 - 16}$ which is the formula of Balmer, slightly modifying the constant term so that the standard wave-lengths of Rowland shall be represented, and substituting $\frac{1}{2}\, n$ for m. The wave-lengths of the lines of hydrogen may be determined by this formula if we substitute for n the even integers 6, 8, 10, 12, etc.

In the annexed table the values of n, the designations of the corresponding lines of hydrogen, their computed wave-lengths, their observed wave-lengths, and the observed minus the computed values are given in the first five columns. If now we substitute for n the odd integers 5, 7, 9, 11, etc., we obtain the wave-lengths of the second series of lines in the spectrum of ζ Puppis, as is shown in the second part of the table. The sixth column gives the value of n, the seventh the corresponding computed wave-length, and the eighth and ninth the wave-lengths of the lines in ζ Puppis as derived from two series of measures. Miss A. J. Cannon has found that the same series of lines occurs in the star 29 Canis Majoris (*H. P.* 1380) whose position for 1900 is R. A. $= 7^h\ 14^m.5$, Dec. $= -24°\ 23'$. As this star has the magnitude 4.8, only three lines of the series are measurable in the photographs so far taken, but, unlike ζ Puppis,

many additional lines are present. Measures of the lines common to ζ Puppis are given in the tenth column of the table and the observed minus the computed values for the two stars are given in the last three columns.

n	Des.	Comp.	H	O—C
4	--	∞	—	....
6	$H\alpha$	6563.0	6563.0	0.0
8	$H\beta$	4861.5	4861.5	0.0
10	$H\gamma$	4340.6	4340.7	— 0.1
12	$H\delta$	4101.9	4101.8	+ 0.1
14	$H\epsilon$	3970.2	3970.2	0.0
16	$H\zeta$	3889.2	3889.1	+ 0.1
18	$H\eta$	3835.5	3835.5	0.0
20	$H\theta$	3798.0	3798.1	— 0.1

n	Comp.	ζ	ζ	29	ζ	ζ	29
5	10128.1	.....	.....	.....	.....	.....	.....
7	5413.9	.....	.....	.....	.....	.....	.....
9	4543.6	R	R	R	.....	.....	.....
11	4201.7	4199.2	4201.6	4201.1	— 2.5	— 0.1	— 0.6
13	4027.4	4027.1	4026.5	4025.4	— 0.3	— 0.9	— 2.0
15	3925.2	3924.6	3924.9	.....	— 0.6	— 0.3	.....
17	3859.8	3858.7	3858.6	.....	— 1 1	— 1.2	.....
19	3815.2	3814.7	3817.2	.....	0.5	+ 2.0	.....
21	3783.4	.....	3783.4	.....	.....	0.0	.....

The wave-lengths here given depend upon the lines of hydrogen and were determined from them by a form of graphical interpolation. The interval between $H\beta$ and $H\gamma$ is so great that the errors of interpolation are large for lines in that part of the spectrum. These errors are still greater in the approximate measures given in *Circular* No. 12, although the results there given for the five lines of the series of shorter wave-length than $H\gamma$ agree closely with those given above. Comparing the spectrum of ζ Puppis with the spectra of other stars, it appears that the four lines between $H\gamma$ and $H\beta$ probably coincide with the lines having wave-lengths 4472, 4544, 4633, and 4688. The first of these lines is very faint and appears to coincide with the

principal line distinguishing stars of the Orion type. The second line is well marked and is the line computed above when $n = 9$. The third and fourth lines are bright and coincide with the principal lines in spectra of stars of the fifth type. These four lines are also present in 29 Canis Majoris. Several of the lines in the above table appear bright in stars of the fifth type. Thus in *H. P.* 1311 the lines for which n equals 8, 9, 10, 11, 12, 13, and 14 are bright. In γ Velorum these lines are also present, some being bright and some dark. The line for which $n = 7$ is one of the most conspicuous in the visual spectra of stars of the fifth type. Its wave-length has been found by Campbell to be 5412.4, which agrees closely with the computed value 5413.9. He also finds the line 4540, which is probably identical with the line for which $n = 9$. From photographs recently taken at Arequipa, but not yet received at Cambridge, it is expected that the wave-lengths of all these lines can be accurately determined.

January 12, 1897.

ON THE SPECTRUM OF ζ PUPPIS.

By H. Kayser.

The Harvard College Observatory *Circular* No. 12 contains a very interesting notice by Professor Pickering on the spectrum of ζ Puppis. Besides some bright lines it shows the hydrogen series and a series of lines hitherto unknown with the wave-lengths 3814, 3857, 3923, 4028, 4203, 4505. I think this series is of the highest interest, because it seems probable to me that we have here another hydrogen series. That the lines form a series was remarked also by Professor Pickering, and he finds that they are represented approximately by the modified formula of Balmer: $\lambda = 4650 \frac{m^2}{m^2 - 4} - 1032$, where m has the value 5 for the last observed line.

After seeing Professor Pickering's *Circular*, I immediately calculated the reciprocals of the wave-lengths and their differences. With the aid of the table given by Kayser and Runge ("Ueber die Spectren der Elemente," *Abhand. d. K. Akad. d. W. Berlin*, 1891, p. 65) it became evident that the last line must really have the number 5, so that it corresponds to the hydrogen line 4342. In plotting on the scale of frequencies the spectrum of hydrogen and the new lines of ζ Puppis, it appears that the lines of the two series lie nearer and nearer together as the order of the lines gets higher. It therefore seems that the ends of the two series would nearly coincide. Now Runge and myself have found that in the spectra of all the elements, where series could be found at all, there were two series ending at nearly the same place. In our formula $\frac{1}{\lambda} = A - Bm^{-2} - Cm^{-4}$ this is expressed by the fact that for the two series of every element A has nearly the same value. Besides these two series the alkalies have a third series, named by us the principal series, the lines of which are situated high in the ultrale-viot compared

with the other two series. Hydrogen has been so far the only element with a single series, and as the principal series contains the most intense lines of every element, it was generally thought that the hydrogen lines were the principal series. But I was never convinced of it: as with decreasing atomic weight all the series recede to shorter wave-lengths, and as the principal series of lithium ends below λ 2300, one would expect to find the principal series of hydrogen in parts of the spectrum hitherto photographed only by Schumann. But if the known series were not the principal series, we should expect to find another series ending at nearly the same point, with lines a little less intense but sharper. Now these conditions are fulfilled by the new series. Professor Pickering's photograph shows very well that every new line is weaker and sharper than the corresponding hydrogen line. The old hydrogen series is represented by the formula $\frac{1}{\lambda} = 27430 - 109721\,m^{-2}$, the new series by the approximate formula $\frac{1}{\lambda} = 27559 - 134054\,m^{-2}$. (I have calculated the constants only by the first and last lines; the method of least squares would, of course, give a closer approximation.) For the two series of lithium the corresponding constants are 28587, 109625, and 28667, 122391. I think this comparison shows that it is not improbable that Professor Pickering has found a new series of hydrogen, not the indication of a new element.

That this series has never been observed before, can perhaps be explained by insufficient temperature in our Geissler tubes and most of the stars.

BONN, Jan. 2, 1897.

ON THE SPECTRA OF HEAVY AND LIGHT HELIUM.

By J. S. Ames and W. J. Humphreys.

Soon after helium was discovered by Professor Ramsay, it was suspected by several spectroscopists that the gas discovered was not pure, but a mixture. Crookes and Lockyer, both, based their opinions on observed irregular changes in the spectrum, but Runge and Paschen, as the result of a most interesting research, brought forward evidence which seemed quite conclusive in favor of the belief that the new gas derived from clèveite was a mixture of two "elementary" gases. It had been shown by Kayser and Runge that in the spectra of many elements there were three series of lines, each series having definite characteristics; and, so, when Runge and Paschen showed by a most elaborate investigation that in the spectrum of cléveite gas there were two independent sets of series, each set including the three characteristic and well-known series, strong evidence was afforded in favor of two elements being present in clèveite gas. Other evidence was also given, partly spectroscopic, partly chemical. One set of series of lines appears much more frequently in the chromosphere of the Sun than does the other; again, after diffusion through a porous plug, one set of series was much weaker than in the natural gas. More recently, in a paper by Ramsay and Collie, in the *Proc. R. Soc.*, 60, 206, the authors show that by a process of diffusion, many times repeated, it is possible to separate helium gas into parts of widely different densities. In one experiment they obtained gases differing in density in the ratio of five to six.

With the spectroscope at their command, Ramsay and Collie were unable to detect any differences between the spectra of the heavy and the light helium; and it is through the kindness of Professor Ramsay that we have had placed at our disposal various specimens of heavy, light, and ordinary helium; so that their spectra might be studied by means of the instruments of

great dispersion in use in the physical laboratory of the Johns Hopkins University.

The tubes which we have examined are marked as follows:

1. Helium and argon.
2. He. II., Ap. 27, 95. W. R.
3. Samarskite, heaviest. Contains air.
4. Samarskite, lightest.
5. Residue from 400^{cc} He. from Samarskite, after at least ten diffusions.

In addition to these we have studied the spectra of two helium tubes which were filled by Professor Ramsay in previous years, and of a third belonging to Professor Remsen, which had been filled with helium, prepared from Samarskite by Professor E. C. Franklin, of the University of Kansas. The spectra were obtained by means of a concave grating, six inches wide, having 15,000 lines to the inch, and a radius of curvature of twelve feet. Both eye and photographic measurements were taken, the discharge was passed both with and without spark-gap, with both large and small current; and *in no case were there any differences observed between the spectra of the various tubes.* Most of the photographs were taken so as to include w.-l. 3600–5030; for in this space there are lines of all the six series observed by Runge and Paschen. The character of the lines, the relative intensities, and the entire appearance of the spectra are in all cases the same, so far as we can judge. It seemed at first as if the helium line, principal series, 3888.785, was different on various plates; but the differences observed proved to be due not to the line itself but to lines exceedingly close to it. It is possible that the difference between heavy and light helium is due to the presence of an impurity, which, although occurring in varying amounts, may still give rise to a strong spectrum.

JOHNS HOPKINS UNIVERSITY,
December 1896.

OXYGEN IN THE SUN.

By Lewis E. Jewell.

In the Astrophysical Journal for December is a short paper by C. Runge and F. Paschen, in which they conclude that probably three lines in the solar spectrum at λ 7772.20, 7774.43, and 7775.62 (Higgs' map) coincide in position with three lines of oxygen produced in the vacuum tube under certain conditions. Mr. McClean had examined the lines upon photographic plates and had concluded that the three lines in question were probably produced in the Sun's atmosphere and not in that of the Earth.

I have examined these lines, using the large plane grating spectrometer at the Johns Hopkins University. The grating is five inches wide and has 15,000 lines to the inch. It is one of the finest gratings ever ruled and wonderfully bright in the red; when it was new I observed lines below λ 8600 in the intra-red. Observations were made on December 23, 24, 25, 27, and 31, 1896 and on January 4, 1897.

On December 31 and January 4 the air was warm and very humid, while upon the other days it was dry and cold.

Some attempts were made to see what effect the Sun's rotation produced upon these lines; but the spectrum is exceedingly weak to the eye when the slit of the spectroscope is placed near the edge of the Sun's disk, so that no satisfactory observations of this character have yet been made. Other observations, however, were so decisive in their character that confirmation by this method is not necessary.

At noon of December 24 with the Sun at an altitude of 27°, the lines at λ 7772.20 and 7774.43 (the strongest lines of the supposed oxygen triplet) were weaker than the lines in the 15th pair in the tail of A (due to atmospheric oxygen). Near sunset, when the Sun's altitude was about 4°, the lines in question were stronger than those of the 14th pair of A. The sunlight at

the last observation passed through five times as much atmosphere as during the former observation, and the lines of atmospheric oxygen had correspondingly increased in intensity. As these comparisons show that the suspected lines had increased much more in intensity than those of atmospheric oxygen used for comparison, it was evident that the suspected lines were unquestionably produced in the Earth's atmosphere but could not be due to atmospheric oxygen. Comparisons were also made with the solar line at λ 7699.1; and, while the suspected lines was *very much* weaker than the solar line at noon, near sunset they were stronger.

Observations were made under similar conditions on December 25 and 27, and the previous results confirmed.

On December 31 the air was warm and very moist. With the Sun at an altitude of 27°, the lines were weaker than those of the 14th pair of A and stronger than those of the 15th pair, being nearer the 14th. Observations made during both the morning and afternoon, when the Sun's altitude was about 15°, showed the lines to be slightly stronger than those of the 13th pair of A. (These results were confirmed by observations of Dr. J. S. Ames.) Observations made later in the afternoon showed that the lines were becoming relatively stronger; but the air was getting hazy and the spectrum weak; so that no reliable estimates could be made, though the lines could be seen until the Sun was about 5° from the horizon.

On January 4, an observation was made with the Sun at an altitude of 27° 30′, and the lines in question were stronger than those of the 14th pair of A but weaker than those of the 13th pair. Observations upon known water-vapor lines showed the humidity of the air to be greater than upon December 31. Clouds however prevented any further observations; but those already made prove conclusively that the three lines supposed to be due to oxygen in the Sun are produced by water vapor in the Earth's atmosphere.

JOHNS HOPKINS UNIVERSITY,
January 4, 1897.

ON THE EFFECT OF PRESSURE IN THE SURROUNDING GAS ON THE TEMPERATURE OF THE CRATER OF AN ELECTRIC ARC. CORRECTION OF RESULTS IN FORMER PAPER.[1]

By W. E. WILSON and G. F. FITZGERALD.

IN May 1895 a preliminary paper by one of the authors was read at the Royal Society, in which is described the apparatus used for these experiments, and the results which were then obtained.

The primary object of this research was to determine, if possible, whether the temperature of the crater in the positive carbon varies when the pressure in the surrounding gas is changed.

It has been suggested that the temperature of the crater is that of boiling carbon. The most modern determinations give this temperature of the crater as about 3300°–3500° C.[2]

If this is the true boiling point of carbon, it is then clear that solar physicists must find some other substance than solid carbon particles to form the photospheric clouds in the Sun, as the temperature of this layer is most probably not below 8000° C.,[3] unless, indeed, the pressure in the solar atmosphere is sufficient to raise the boiling point of carbon to about this temperature. It is in order to throw some light on this subject that these experiments were undertaken.

The gas used in our first experiments was nitrogen, and we found that the radiation from the crater fell off in a most remarkable manner whenever the pressure was raised in the box surrounding the arc. This falling off was not due to any very large extent to visible cloud or smoke, and the crater seemed so much reduced in temperature as to glow with only a red heat. This seemed to show that the temperature of the crater depends

[1] Read before the Royal Society.

[2] WILSON and GRAY, *Proc. R. Soc.*, **58**; Violle, *Jour. de Phys.*, 3d series, **2**.545.

[3] WILSON and GRAY, *Phil. Trans.*, A, **185**, 1894.

on how much it is cooled by the surrounding gas, and not on its being the temperature at which the vapor of carbon has the same pressure as the surrounding atmosphere.

It was found that we were limited to pressures not exceeding about 20 atmospheres, as at this pressure we could not withdraw the negative carbon sufficiently to see into the crater without the arc breaking. We were then only able to obtain a current from a battery of accumulators which had an E.M.F. of 110 volts. Since then we obtained a Crompton dynamo which could give 300 volts and 15 amperes, and which was driven by a turbine.

From the great difficulty of obtaining a sufficient quantity of pure nitrogen under pressure, we obtained a 20-foot cylinder of air compressed to 120 atmospheres. With this we tried a series of experiments, and these at first seemed to corroborate our former ones, in which we used nitrogen, but we found that at any rate some of the radiation, and possibly a great deal of it, was cut off by the formation of what appeared to be red fumes of NO_2. We found no absorption from this cause so long as the pressure was nearly atmospheric, but at about 100 pounds pressure this gas was formed with great rapidity, and undoubtedly cut off a great deal of the radiation. We easily confirmed our belief in the presence of this gas by its well-known absorption spectrum.

Lest heat dissociation might cause an apparent increase in the amount of NO_2, we tried heating some of this gas in a flask. We observed that when hot the brown fumes became golden yellow, and the absorption bands nearly disappeared, so that the heating could *not* have been the cause of the apparently enormous production of NO_2 at high pressure.

We next tried whether oxygen blown into the arc would burn up the carbons, but found it did not do so to any serious extent, and so tried the arc in a compressed atmosphere of this gas.

The arc burned very nicely indeed in the oxygen, the carbons keeping a good shape and a very steady crater. The oxy-

gen was, however, so contaminated with nitrogen that at high pressure enormous quantities of NO_2 were again formed, so that we could not proceed further with the radiation experiments. The arc was a bright blue bead, about the size of a pea, and the spectrum was a beautiful banded one.

From these results we concluded that the reduction of radiation and red-hot appearance of the crater in the former experiments in nitrogen were due to its being contaminated with oxygen, and to the large quantities of NO_2 which were formed by the arc when under pressure.

We next tried the arc in hydrogen. The gas was obtained as pure, but contained hydrocarbons as an impurity, possibly from having been compressed into a cylinder which had previously been charged with coal-gas.

The arc in hydrogen at atmospheric pressures was a long, thin flame, that moved as far up the carbons as possible; especially on the negative carbon it walked up a centimeter along the cone. It went so far that it fused the copper ring that held the negative carbon, and we had to replace it by an iron wire lashing. It was very unsteady, and trees of soot and a deposit of hard graphitic carbon formed on this positive carbon as if there were electrolysis of the hydrocarbon, and carbon were electro-negative compared with hydrogen. This growth took place all round the crater, while there was no tendency for anything to grow on the negative carbon.

The arc was only 5–6^{mm} wide, and sometimes over 2^{cm} long. There was a green outer flame, with a bright red line not 1^{mm} wide down the middle of it. Where it impinged on the negative carbon there was a bright red flame from the middle of the bright spot on the carbon. The outer greenish part seemed to give much the same spectrum as the green cone in a Bunsen burner, while the red flame and line was undoubtedly glowing hydrogen. As we saw the C and F hydrogen lines very distinctly, the red C line being dazzlingly bright and not nearly so wide as in a coil spark at atmospheric pressure whenever the image of the red part of the arc was thrown on the slit of the

spectroscope, the appearance was quite like that of a solar prominence.

The end of the positive carbon was pitted into a number of craters, as the arc was very unsteady, and when the pressure was raised it was almost impossible to keep an arc going, partly because the arc broke when it was elongated the least bit, and partly because a complete lantern of soot trees grew all round the crater, and seemed to short circuit the arc from time to time.

The arc being very unsteady, no satisfactory reading of the voltage and current was possible. At from 60 to 80 pounds pressure the voltage varied from 60–80, and the amperes kept continually varying from 15–20. At 40 pounds with 20 amperes the volts varied from 50–60. The crater was not well developed, so that the radiation observation, even at low pressures, was not very satisfactory, while at high pressures the arc was too short to see into the crater at all, and the lantern of soot trees hid a considerable length, 3^{mm} or 4^{mm}, of the negative carbon besides. The radiomicrometer gave 440 divisions with a good arc in air, and 380 with the moderately good crater in hydrogen. But this difference is no greater than would often occur with a good and moderately good crater, so that there is not any proof of a difference of temperature due to cooling power of hydrogen. These experiments showed us that it was quite hopeless to get any measures of radiation under pressure with hydrogen.

We finally tried an atmosphere of carbon dioxide. We used a cylinder of liquid CO_2, which was connected to our arc box by a copper tube and stop valve. The arc burned fairly well in this gas, and, except for the difficulty of getting a sufficiently long arc at pressures above 150 pounds, some pretty satisfactory measures of radiation were obtained. We found that whenever the pressure was suddenly reduced there was a fog formed in the box, which cut off the light enormously. Also by looking down the steel tube, which is closed at its end by a lens, we could see powerful convection currents in the gas which scattered a lot of light. At high pressure the refraction due to these currents prevented any sort of an image of the crater being formed

while the pressure was varying. While the pressure was steady a good image could be formed. This tube is nearly 3 feet in length, and only one-half inch in bore, and it would naturally take time for the gas to settle down throughout its length. We propose to have this tube removed, and the aperture in the box closed by a strong piece of plane glass, and to form an image of the carbons by a lens placed at a suitable distance outside. This we expect will remove the difficulty arising from these convection currents.

The result of all these experiments so far is that it would require more evidence than we have been able to get to affirm that either the temperature of the crater of the arc is raised or lowered by pressure. We got some very concordant observations, which showed the temperature to be lowered with pressure, and in which at the time we could see no evidence of absorption by fog; but then, at other times, there was undoubtedly absorption from this cause. We certainly got no evidence that there is any appreciable increase of temperature. When the arc was started in the gas at a low pressure and then the pressure was raised, the radiation at the low pressure was greater than at high pressure; but when the arc was started first in the gas at high pressure, and then the pressure reduced, the radiation was rather higher in the gas at high pressure. From all this we concluded that the greater part of the differences we were observing were due to the absorption of the light in the long tube already mentioned, which increased the longer the arc was kept burning, and was probably greater at high than at low pressures. The best observations were made with variations of pressure from 15 up to 100 pounds per square inch, and there seems very little evidence of much change of radiation with this change of from 1 up to between 6 and 7 atmospheres.

The whole question is surrounded with great difficulty. If the carbon be really in equilibrium with its own vapor at the temperature of the crater and at the pressure of the surrounding atmosphere, some relation must exist between the change in pressure and change in temperature of the crater. If we knew

the latent heat of volatilization of carbon, we should be able to calculate the change of temperature from the well-known thermodynamic formula

$$\frac{\delta T}{T} = \frac{\Delta v}{\lambda} \cdot \delta p.$$

Δv can certainly be approximately determined on the supposition that the absolute temperature of the crater is fifteen times the absolute temperature of the freezing point, *i. e.*, 3800°. We thus get for gaseous carbon $\Delta v = 10^4 qp$ at this temperature. For 1 atmosphere $\delta p = 10^6 qp$, so that

$$\frac{\delta T}{T} = \frac{10^{10}}{\lambda}.$$

Hence, unless the latent heat of carbon be enormously great compared with that of other substances, $\delta T / T$ will be considerable. If λ be as great as the latent heat of vaporization of carbon given by Trouton's law, *i. e.*, about 4000 calories, or 16.8×10^{10} ergs, $\delta T / T$ will be about $\frac{1}{17}$, and δT will be nearly 220° C. for each atmosphere, and a change of pressure of about 18 atmospheres would raise the temperature of the crater to that estimated for the Sun. The corresponding increase of radiation would be very great, for the radiation varies, at least approximately, as the fourth power of the absolute temperature. This would lead one to expect that the radiation would be nearly doubled for each 4 atmospheres added. Such an increase as this certainly does not take place, so that we may conclude that either the temperature of the crater is not that of boiling carbon, or else that the latent heat of volatilization of carbon is very considerably greater than that calculated from Trouton's law. Even though this latent heat were as great as the heat of combustion of C to CO_2, *i. e.*, 7770, there would be an increase of about 70 per cent. in the radiation for an increased pressure of 6 atmospheres. Such an enormous latent heat is unprecedented, and yet our experiments would almost certainly have shown such an increased radiation as this. So far, therefore, the experiments throw considerable doubt on the probability that it is the boiling point of carbon that determines the temperature of the crater. It might be

questioned whether there is energy enough in the current to do all this work, but upon an extravagant estimate of the amount of carbon volatilized in the crater, it appears that there is more than a hundred times as much energy supplied by the current as would be required for volatilizing the carbon, even though its latent heat were as great as the heat of combustion of C into CO_2.

There is another considerable difficulty in the theory of the temperature of the crater being that of boiling carbon arising from the slowness of evaporation. The crater on mercury is dark, but then it volatilizes with immense rapidity and the supply of energy by the current being more than 100 times that required merely for evaporation, there seems very little reason why even a considerable difference in latent heat should make any sensible difference in the rate of evaporation of mercury and carbon, especially as, at the same temperature, the diffusion of carbon vapor is nearly three times as fast as that of mercury vapor and the temperature immensely higher.

We would, in conclusion, call attention to a cause of opacity in the solar atmosphere that is illustrated by the effect of convection currents in the long tube we were observing at high pressures; these convection currents behaved just like snow, or any other finely divided transparent body immersed in another of different refractive index. Light trying to get through is reflected backwards and forwards in every direction, until most of it gets back by the way it came. The consequence was that even the electric arc light was unable to penetrate the tube at high pressure, when these convection currents were active. The only light that came out of the tube was the feeble light outside, which was returned to us by reflection at the surfaces of these convection currents. In a similar manner we conceive that any part of the solar atmosphere which is at a high pressure, and where convection currents, or currents of different kinds of materials, are active, would reflect back to the Sun any radiations coming from below, and reflect to us only the feeble radiations coming from interplanetary space. In his paper on "The Physical

Constitution of the Sun and Stars" (*Proc. R. Soc.*, No. 105, 1868), Dr. Stoney called attention to an action of this kind that might be due to clouds of transparent material, like clouds of water on the Earth, but in view of the high solar temperature it seems improbable that any body, except perhaps carbon, could exist in any condition other than the gaseous state in the solar atmosphere; so that it seems more probable that Sun-spots are due, at least partly, to reflection by convection streams of gas, rather than by clouds of transparent solid or liquid particles.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XVII.

By Henry A. Rowland.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3439.735		000 N	3444.217		0000
3439.841		0000	3444.402	Ni?	2
3439.941		0000	3444.467	Ti	4
3440.008	Fe	3	3444.590		0000 N
3440.138		000 N	3444.654		0
3440.235		00 N	3444.774		0000
3440.328		000 N	3444.847		00
3440.505		0 N	3445.030		000 Nd?
3440.635		000 N	3445.260	Fe	5
3440.762 S	Fe	20	3445.477		000 N
3440.875		00 N	3445.597		000 N
3441.021		000 N	3445.741	Fe, Cr	2 N
3441.155 S	Fe	15	3445.905	Fe	2
3441.248		000 N	3445.947		0000
3441.391		0 Nd?	3446.127		0000
3441.588	Cr	1 N	3446.240		1
3441.688	Pd	0000 N	3446.314		000
3441.808		0000 N	3446.406	Ni	15
3441.875		000	3446.536		1 Nd?
3442.035		0000	3446.620		0000 N
3442.118	Mn	6	3446.747		0000 N
3442.188	Ni	1	3446.857		000
3442.284		1	3446.931		00
3442.368		00	3447.089		0
3442.503	Fe	2	3447.154		00 N
3442.696	Ni	0	3447.290		0000 N
3442.813	Fe	3	3447.420	Fe, Co	4
3442.921		0000	3447.569	Cr	0
3443.059	Co	2	3447.674		0000 N
3443.101	Fe	1	3447.774		000
3443.181		00	3447.901	Cr	0
3443.330	Co	0	3448.040		0000 N
3443.435		000 N	3448.144		1
3443.517		1	3448.227		0000
3443.575		0000 N	3448.340		0 Nd?
3443.691		0000	3448.494		000 N
3443.791	Co	5 d?	3448.597		000 N
3443.908		00 N	3448.727		000 N
3444.020 S	Fe	8 N	3448.827		0000 N
3444.127		0 N	3448.926		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3449.003		0	3455.736	Cr	0
3449.099		0000	3455.828		0000 N
3449.186		0000	3455.928		0000Nd?
3449.310	Co	5 d?	3456.081		0000
3449.446		0000	3456.148		00
3449.583	Co	6 d?	3456.228		000
3449.766		0000 N	3456.383	Fe	0
3449.833		0000 N	3456.528	Ti	3
3449.996		000 Nd?	3456.634		0000 N
3450.123		000 Nd?	3456.714		0000 N
3450.275		00	3456.801	Ti	00 N
3450.373		0000 N	3456.944		000 N
3450.469	Fe	5	3457.068	Co	1
3450.589		0000 N	3457.230	Fe	2
3450.742		0000 N	3457.281		00
3450.882		0000 N	3457.414		0000 N
3450.995		000 N	3457.538		0000 N
3451.129		0000	3457.648	Fe, Zr	0
3451.255		00	3457.708		0
3451.369		0000	3457.758		000
3451.477		0	3457.908		0000 N
3451.609	Mn	0	3458.028		0
3451.761	Fe	2	3458.144		000
3451.915		0000 N	3458.254		0
3452.057	Fe	3	3458.442	Fe	3
3452.419	Fe	4	3458.601	Ni	8
3452.609	Ti	1	3458.728		0 N
3452.762		000	3458.834		0 Nd?
3452.919		00 N	3459.074	Zr	00
3453.039	Ni	6 d?	3459.194		0000
3453.169	Fe	2	3459.288		000
3453.255		000	3459.414		000
3453.355	La	0000	3459.568	Fe	2
3453.469	Cr	0	3459.714		0000
3453.621	Co	3	3459.761		0000
3453.705		2	3459.881	Fe	1
3453.885		00	3460.052	Fe	3 d?
3453.982		0000 N	3460.174	Mn.	2
3454.303	Ti	1	3460.294		0000
3454.455		00	3460.460	Mn.-	4 d?
3454.602		0000 N	3460.568	Cr	000
3454.725		000 N	3460.691		0000 N
3454.829		0000 N	3460.741		0000 N
3454.934		0000 N	3460.874	Pd	00
3455.058		0000	3461.021		000 N
3455.121	Mn	000	3461.141		00
3455.204	Mn	000	3461.321	Co, La	0
3455.379 S	Co	5	3461.413		0000 N
3455.494		0000 N	3461.633	Ti	5
3455.601		0000 N	3461.801	Ni	8

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3461.930		0 N	3468.612		0 N
3462.073		00 N	3468.821		1
3462.217		0000 Nd?	3468.986	Fe	2
3462.347		000	3469.114		0
3462.492	Fe	1	3469.155	Fe	2
3462.667		0000 Nd?	3469.532		0
3462.867		00 N	3469.628	Ni	3
3462.950	Co	6	3469.736	Cr	0
3463.153	Zr	0	3469.826		0000 N
3463.323		0000 N	3469.972	Fe	2
3463.444	Fe	1	3470.076		0000
3463.520		0000	3470.156		0000
3463.660		0000 N	3470.276		0000 N
3463.777		0000 Nd?	3470.380		000 N
3463.937		0000 Nd?	3470.536		00
3464.113		2	3470.678		0
3464.167		00	3470.776		0000
3464.275	Fe	1 d?	3470.876		00
3464.608 s		1	3471.000		0000
3464.843		000	3471.136		0000
3464.970		0000	3471.256		000
3465.052	Fe	0	3471.404	Fe, Zr	3
3465.167		0000	3471.499	Fe, Co	3
3465.300		0000	3471.598		0
3465.390	Cr	00	3471.750		000
3465.467		0000 N	3471.856		000
3465.573		0000 N	3471.910		0000
3465.687		1	3472.035		1 N
3465.779		1	3472.190		00 N
3465.900 } s	Co	4	3472.316		0 N
3466.015 }	Fe	6	3472.443		00 N
3466.137		00 N	3472.593		0
3466.187		00 N	3472.680	Ni	{ 5
3466.320		00	3472.730		{ 2
3466.420		0	3472.850		0000 N
3466.507		0000 N	3472.916		000
3466.639	Fe	3	3473.040		000
3466.773		0	3473.146		000
3466.853		0000	3473.190		0000
3467.033	Fe	2	3473.363		0000
3467.153		000 N	3473.435	Fe	2
3467.270		000 N	3473.637	Fe	1
3467.407	Ti	00	3473.756		0
3467.517		0000 N	3473.823	Fe	1
3467.644	Ni	3	3473.950		0000
3467.845	Ni, Cr	2	3474.106	Co	2
3468.007		000	3474.197	Mn	2
3468.210		00	3474.287	Mn	2
3468.347		0000 N	3474.410		0000
3468.486		0000 N	3474.523		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3474.576	Fe	2	3480.549		000
3474.669		00	3480.669	Ti	1
3474.800		000	3480.785		0000 N
3474.904		1	3480.875		0000 N
3475.023		00	3481.024	Ti	2
3475.143		0000 N	3481.195		00 N
3475.270		2	3481.302	Pd, Ti-Zr	2
3475.406		0	3481.439	Cr	0
3475.456		00	3481.589		0000
3475.594 s	Fe	10	3481.695	Fe, Cr	2
3475.656		0 N	3481.802		0000
3475.802	Fe	2	3481.889		000
3475.894		1	3481.952	Fe	00
3476.010	Fe	2	3482.075		000
3476.163		000 N	3482.195		000
3476.330		0000 N	3482.325	Fe	1
3476.479	Co, Fe	3	3482.589		000
3476.590		0000	3482.712		000 Nd?
3476.756		0	3482.855	Zr	00
3476.849 s	Fe	8	3483.047	Mn-	5 d?
3477.002	Fe	1	3483.155	Fe	4
3477.125	Fe, Ti	3 d?	3483.295		0000
3477.323	Ti	5	3483.553	Co	3
3477.500		000	3483.667	Fe, Zr	0
3477.636		00	3483.769		000
3477.770		0	3483.923	Ni	6 d?
3477.856		0000	3484.023		1
3478.002 s	Fe, Ni	4	3484.172		0000 N
3478.123		000	3484.295		3
3478.256		0000 N	3484.352		00
3478.316		0000 N	3484.482		000 Nd?
3478.438	Ni, Zr	0	3484.602		0000Nd?
3478.504	Fe	0	3484.809		0000 N
3478.689	Co, Zr	0	3484.922		00
3478.772	Fe	1	3484.995	Fe	1
3478.876		0000	3485.121	Fe	2
3478.923	Co	0	3485.249		1
3479.053		000	3485.360		0000 N
3479.163	Zr	0	3485.493	Fe Co	6
3479.273		0000	3485.645		0000 N
3479.401	Ni	1	3485.719		0000 N
3479.531	Zr	2	3485.845		00 N
3479.703		0000 N	3486.041 s	Ni	5
3479.829	Fe	1	3486.179		0000
3479.969		0	3486.282		0000
3480.061		1	3486.362		000
3480.171		00	3486.475		000
3480.315	Ni	1	3486.522		0000
3480.442		0000	3486.691	Fe	2
3480.476	Fe, Zr	2	3486.782		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3486.889		0000	3493.313		0 N
3486.962		0000	3493.430	Ti, Fe	1
3487.095	Mn	00 N	3493.618		2
3487.145		0000	3493.721		00
3487.289		0000	3493.834	Fe	1
3487.415		0000	3494.004		00
3487.542		000	3494.154		0000 N
3487.743		2	3494.308	Fe	2
3487.857	Co, Ca	0	3494.401		0000
3487.959		000	3494.498		0000
3488.131		2	3494.551		0000
3488.289		0000 Nd?	3494.654		0
3488.437	Ni, Mn	0	3494.815	Fe	2
3488.589		000	3494.871		000
3488.702		0000 N	3494.994		0000 N
3488.817	Mn	4	3495.108	Cr	00
3488.965		1	3495.178		0000 N
3489.142		00 Nd?	3495.384		0
3489.302		00 N	3495.423	Fe	3
3489.392		0000 N	3495.522		2
3489.546	Co	5	3495.658		000
3489.813	Fe	3	3495.802	Co	3
3489.889	Ti, Pd	2	3495.853	Ti	2
3490.048		0000	3495.974	Mn	2
3490.104		0000	3496.024	Fe	2
3490.191		0000	3496.101		0000
3490.301		0	3496.224	Co	0
3490.341		0000	3496.348	Zr	2
3490.441		0000	3496.491	Ni	0
3490.534		00	3496.614		0000 N
3490.628		0	3496.721		0
3490.733 S	Fe	10 N	3496.820	Co	3
3490.896	Co	0	3496.952	Co, Mn	3
3491.008		000 Nd?	3497.148		1
3491.195	Ti	5	3497.241 } S	Fe	3
3491.354		000	3497.301 }		2
3491.462 S	Co,-	4	3497.421		0000 N
3491.661		0000 N	3497.534		0
3491.894		000	3497.668	Mn	3
3492.021		0000 N	3497.874		0 N
3492.112	Co	00	3497.982 S	Fe	8
3492.174		0000	3498.116		0
3492.284		0000	3498.322		1 N
3492.368		000 N	3498.451		0000 N
3492.508		00 N	3498.534		0000 N
3492.678		000 N	3498.668		00
3492.858		000 N	3498.888		1
3492.954		00 N	3499.084		00
3493.114	Ni	10 N	3499.248	Ti	0
3493.228		000 N	3499.408		00

Wave length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3499.492		0	3505.371		0000
3499.608		0000 N	3505.433		0
3499.711		0	3505.525		0000
3499.848		0000 Nd?	3505.628	Zr	0
3499.974		0000	3505.810	Zr-V	1
3500.013		0	3505.928		0000
3500.131		000	3506.038		0
3500.296		0	3506.189		000
3500.474	Ti	3	3506.380	Fe	1
3500.577		0000	3506.467	Co	5
3500.706 s	Fe	2	3506.645	Fe	3
3500.830		0000 N	3506.733	Ti	1
3500.996 s	Ni	6 d?	3506.793		0000
3501.094		0000	3506.891		0000
3501.210		0000	3506.980		0
3501.296		0000	3507.077		0000
3501.394		0000	3507.284		2
3501.472		000	3507.350		0
3501.605		000 N	3507.447		0000
3501.710		0000 N	3507.543	Fe	1
3501.841		0	3507.687		0000 N
3501.868		0	3507.837	Ni	3
3501.970		000 N	3507.957		000
3502.104		000 N	3508.090		00
3502.165		0000	3508.234		000
3502.394		{ 3	3508.350		1
3502.466	Co	{ 3	3508.487		0000 N
3502.608		00	3508.626	Fe	3
3502.737	Ni	2	3508.670	Fe	2
3502.775	Co	2	3508.847		0000 N
3502.899		0000	3509.037		00
3503.001		00	3509.157		0000
3503.112		0000	3509.264	Fe	2
3503.256		000 N	3509.470		0000
3503.442		000 N	3509.570		0000
3503.612		1	3509.690		0000
3503.699		0000	3509.870		1
3503.866	Co	00 Nt?	3509.992	Co, Fe	4
3504.048		00	3510.209		000
3504.192		0000	3510.331		1
3504.332		0000	3510.466	Ni	8
3504.399		0000	3510.596	Co, Fe	2
3504.581	Fe, V	2	3510.693		00
3504.733		0000	3510.824		1
3504.823		1	3510.985 s	Ti	5
3504.885	Co	0000	3511.209		0000 Nd?
3505.015	Fe	3	3511.356		0000
3505.056	Ti	2	3511.453		0000
3505.202	Fe	3	3511.583		0000
3505.288	Co	0000	3511.676		0000

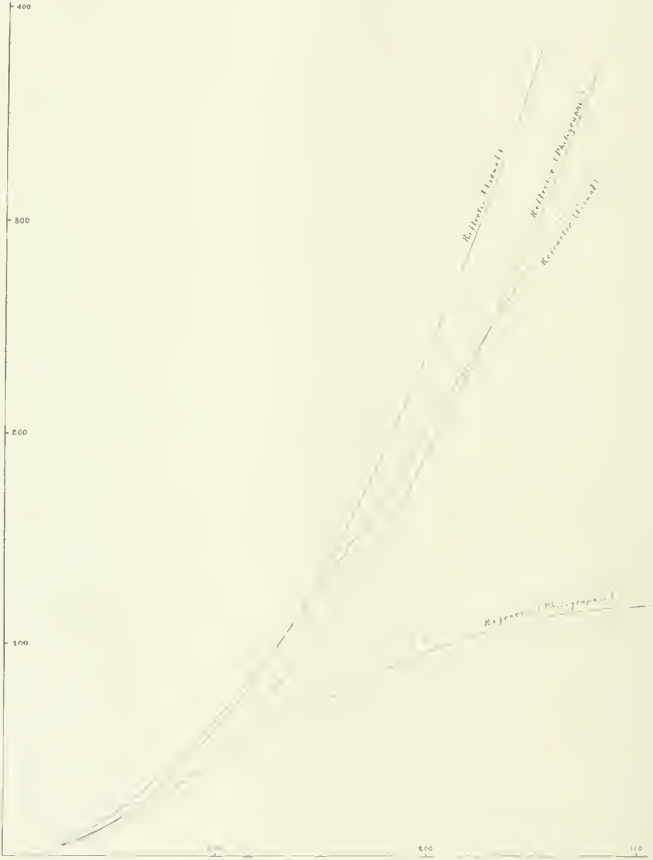
Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3511.763	Mn	0	3518.790	Ni	4
3511.883	Fe	1	3518.825	Fe	3
3511.978	Mn	2	3518.933		0000
3512.066		00	3519.014	Ti, Fe	3
3512.228	Fe	1	3519.239	Tl?	0000Nd?
3512.369	Fe	2	3519.531		0000
3512.520		000	3519.645		0000
3512.639		0000	3519.758		0000
3512.785	Co	6	3519.904	Ni	7
3512.869		00	3520.021		0000
3512.950	.	00	3520.168		2
3513.100	Fe	1	3520.228	Co	3
3513.200	Fe	2	3520.397	Ti	2
3513.422		0000 N	3520.531		0000
3513.623	Co	5	3520.675	Fe	000
3513.744		000	3520.751		0000
3513.868		00	3520.871		0000
3513.965 s	Fe	7	3520.991	Fe, Zr	2
3514.082		4	3521.118		0000
3514.138	Ni	3	3521.205		0
3514.382		0000 N	3521.318		00
3514.608		0	3521.410 s	Fe	8
3514.775	Fe	2	3521.686		3
3515.206	Ni	12	3521.748	Co	4
3515.549		0	3521.888		000
3515.675		00	3521.984	Fe	2
3515.787		0000	3522.184		0000
3515.947		0000 N	3522.284		0000
3516.021		0000 N	3522.412	Fe	4
3516.156		000	3522.589		00
3516.261		0000	3522.677		0000
3516.359	Ni	2	3522.757		0000
3516.441		0000	3522.877		000
3516.554	Fe, Co	2	3522.974		000
3516.701	Fe	2	3523.048	Fe, Co,-	2
3516.854		0000	3523.212	Ni	1
3516.959		0	3523.324		0
3517.093	Pd	00	3523.452	Fe	2
3517.173		0000	3523.584	Co	4
3517.310		0000 N	3523.700		000
3517.446	-,V	3	3523.850	Co	0
3517.523		0000	3523.924		0000
3517.653		000 N	3524.130		000
3517.860		0000 N	3524.221	Fe	3
3517.960		0000 N	3524.385	Fe	3
3518.103		0000	3524.499		0
3518.200		0000	3524.677	Ni	20
3518.360		0000	3524.883		1
3518.488 s	Co	5	3525.063		000 N
3518.636		0000	3525.271		000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3525.416		0000	3532.143	Mn	4
3525.529		0000	3532.262	Mn	3
3525.656		0000	3532.469		000
3525.759		2	3532.601		0000
3525.986	Fe	4	3532.721	Fe,-	4
3526.103		00	3532.777		00
3526.183	Fe	6	3533.041		0000
3526.311		3	3533.156	Fe	6
3526.398	Fe	2	3533.345	Fe	6
3526.526	Fe	2	3533.506	Co	5
3526.625		2	3533.680		0000
3526.686		0	3533.836	V	000
3526.821	Fe	4	3534.000	Ti	1
3526.988	Co	6	3534.206		0000
3527.115		0	3534.400		000
3527.252		00	3534.672	Fe	2
3527.368		0000	3534.733		0000
3527.458		000	3534.830		0000
3527.588		0000	3534.920	Co	000
3527.672		000	3535.060	Fe	3
3527.750		1	3535.090		00
3527.936	Fe	5	3535.180		0000N
3528.041		0	3535.300		0000 N
3528.133	Ni	4	3535.446	C	000
3528.382		0	3535.554	Ti	4
3528.465		00	3535.660		0000
3528.552		0000	3535.766	C	000
3528.715		0000 N	3535.868		3
3528.928		0000	3535.989		0000
3529.035	Ni	1	3536.165		00
3529.181	Co	3	3536.259		0000
3529.328		00	3536.405		0000 N
3529.495		00	3536.709	Fe	7
3529.662	Fe	2	3536.832		0000
3529.768	Ni	1	3536.934		00
3529.872		00	3537.025		0000
3529.964	Fe-Co	6	3537.105		00 N
3530.136		0000	3537.265		0000Nd?
3530.264		0000	3537.385	Ni, C	1
3530.374		0000	3537.439		0000
3530.533	Fe-	3	3537.638	Fe	2
3530.734	Ni, Ti	1	3537.772	Co	0
3530.919		3	3537.879	Fe	3
3531.107		00	3538.045	Fe	4
3531.247		0000 N	3538.219		0000 N
3531.424		0000 N	3538.399		1
3531.582	Fe	2	3538.452	Fe	1
3531.761		0000	3538.555		0000
3531.851		1	3538.643		1
3531.982	Mn	3	3538.701	Fe	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3538.832		0000	3544.888		0000
3538.937	Fe	1	3545.001		0000
3539.081	C	00	3545.054	C	000
3539.218	C	00	3545.128	C	000
3539.391		0000	3545.194		0000
3539.513		0000	3545.336 s	–, V	4
3539.588		000	3545.481		0000 N
3539.684		0000	3545.654	C	0
3539.771		0000	3545.786	Fe, C	5
3539.892		00	3545.971	Fe, C	3
3540.038	C	00 N	3546.048		0000
3540.098		0000	3546.161		0000
3540.268 s	Fe	5	3546.348		1
3540.464	C	000	3546.488		0000
3540.538		000	3546.568		0000
3540.644		0000 N	3546.684		00
3540.857	Fe	3	3546.851	Co	00
3540.950	Fe	2	3546.921		000
3541.108		00 N	3546.974		000
3541.237	Fe	7	3547.121		0000
3541.384		00 N	3547.168	Ti	0
3541.474		000	3547.320		3
3541.687	C	000	3547.362	Fe	3
3541.790		0000	3547.511		0000Nd?
3542.017	C	000	3547.640		0000
3542.129	Ni	0	3547.780		000 N
3542.232	Fe	6	3547.941	Mn	5
3542.397	Fe	3	3548.087		00
3542.473		0000	3548.175	Mn, Fe	3
3542.583		0000	3548.332	Mn, Ni	5
3542.633		0000	3548.447		0000
3542.713	Ti	00	3548.593	Co	00
3542.775	Zr	00	3548.687		000
3542.910		0000 N	3548.793		0000
3543.090		0000	3548.880		0000
3543.143		0000	3549.047		0000 N
3543.243		0000	3549.151 s	Y ?	2
3543.310		0000	3549.260		0000
3543.407	Co	2	3549.384		1
3543.531	Fe	2	3549.513	C	0
3543.637		0000	3549.667	C	00
3543.824	Fe	3	3549.773		0000
3543.937		0000	3549.907		0000Nd?
3544.075	C	0000	3550.014 s	Fe	3
3544.155	C	000	3550.247		0000
3544.229		0000	3550.363	C	1 N
3544.371		1	3550.510		000
3544.489		0000	3550.627	C	0000
3544.662		000	3550.740	Co	4
3544.776	Fe	3	3550.939	C	000 Nd?

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3551.092	C	0000 N	3557.036		3
3551.253		1	3557.204		0000
3551.370	C	000	3557.304		000
3551.542		000	3557.370		000
3551.674	Ni	4	3557.495		00
3551.800		1	3557.604		0000
3551.912		0000	3557.817		0000
3552.012		0000	3557.907		0000
3552.098	Zr	1	3558.020		0000 N
3552.253	Fe	2	3558.140		0000
3552.449		0000 N	3558.214		1
3552.574		0	3558.350		000
3552.699		0000	3558.477		00 N
3552.866	Co	1	3558.570		0 N
3552.986	Fe	5	3558.672 s	Fe	8
3553.086		000	3558.774		0 N
3553.132	Co	1	3558.923	Co	1
3553.236		000	3559.017		0000
3553.304	Pd	00	3559.124		0000
3553.416		0000	3559.219	Fe	1
3553.491		0000	3559.347		00
3553.624	Ni	3	3559.414		0000
3553.735		0000	3559.604		1
3553.887	Fe	5	3559.656	Fe	3
3554.011		000	3559.750		0000
3554.115		0000	3559.840		0000
3554.263	Fe	5	3559.954		000
3554.418		000	3560.063	Ni	0
3554.438		0000	3560.216		00
3554.593		2	3560.303		000
3554.651	Fe	3	3560.436		000 N
3554.789		1	3560.556		000
3554.938		0 N	3560.649		0000
3555.079	Fe	9	3560.729		1
3555.185		0 N	3560.843	Fe	2
3555.318		000 N	3560.942		0000
3555.425		0000	3561.037	Co	4
3555.498		0000	3561.203		0000
3555.598		2	3561.276		0000
3555.758		0000	3561.419		0000
3555.865		0000	3561.516		0000
3555.945		0000	3561.600		0000
3556.088		000 Nd?	3561.718	Ti	1
3556.291		000	3561.796		0000
3556.405		0000	3561.898	Ni	3
3556.515		0000	3562.043	Fe, Ti	1
3556.631		0000	3562.161		0000
3556.738	Zr	2	3562.236	Co	0 N
3556.830	Fe	2	3562.331		0000
3556.944	Fe	4	3562.410		1

PLATE III.



LIGHT GRASPING POWER OF OBJECTIVES AND SPECULA.

ON THE COMPARATIVE VALUE OF REFRACTING AND REFLECTING TELESCOPES FOR ASTROPHYSICAL INVESTIGATIONS.

By George E. Hale.

Every astrophysicist whose investigations include the spectroscopic study of both the Sun and the stars, must have frequent occasion to contrast the instruments available for use in these two fields of research. In the case of the Sun, the brightness of its light permits the employment of finely ruled gratings of very high resolving power, by means of which it is possible to detect a motion of fifty meters per second in the line of sight. For the production of stellar spectra, on the contrary, the most powerful spectrographs used with the largest telescopes contain no more than three large prisms. With the modest resolving power of such an optical train surprisingly concordant measures of stellar motions have been made by the aid of photography, and investigations of this character can be advantageously prosecuted for many years to come. But those who wish to materially reduce the probable error of wave-length determinations of lines in stellar spectra, either for the purpose of increasing the accuracy of line of sight measurements or to render possible such detailed studies of certain lines as are now made in the solar spectrum, must be content to wait for the construction of telescopes much larger than the great instruments of the present day. It thus becomes a matter of importance to the astrophysicist to consider just what advances in telescope construction are most likely to assist him in his work. Naturally the first question that arises is this: Which form of telescope is the better adapted to stellar spectroscopic and other astrophysical investigations — the refractor or the reflector? It is the purpose of the present paper to point out some of the more important advantages for many classes of astrophysical work which the reflecting telescope seems to possess.

For the sake of preventing possible misapprehension, I wish to point out that the observations for which the reflector seems to be best suited should be sharply distinguished from those for which the refractor has been shown by experience to be the better instrument. In direct visual observations requiring perfect definition the refractor seems to give much better results than the reflector. This may be due to a variety of reasons, of which the most potent seems to be the peculiar sensitiveness of a speculum to variations of temperature and flexure. It is not unlikely that the difficulties due to flexure can be done away with by adopting some such form of support for the speculum as that devised by Mr. G. W. Ritchey, optician of the Yerkes Observatory, which is described on another page.[1] The deformation of the mirror resulting from temperature changes cannot be so easily overcome, but its effect upon the image can be lessened by selecting glass as homogeneous as possible for the speculum, so that the distortion may be of a uniform character. But whether the reflector can be ultimately made to compete with the refractor in direct visual observations it is not my object to discuss at the present time. The work for which the reflector seems to be best adapted includes stellar, planetary, and nebular spectroscopy, photometric, and other radiometric studies of the Moon and planets, and photography of stars and nebulæ; it is to the needs of such observations that special consideration is given in this paper.

For such investigations it may said that the perfection of definition required, for example, in double star observations, is to a large extent superfluous.[2] It cannot be doubted that the reflector, even in its present form, defines quite well enough for all work of this character. In stellar spectroscopy, for instance, the unsteadiness of the stellar image on the slit, due to atmospheric disturbances, is ordinarily such as to completely mask any outstanding spherical aberration. Moreover, the sharpness

[1] See p. 143.

[2] See in this connection Professor Wadsworth's remarks in this JOURNAL, May 1896, p. 347.

of the spectral lines depends only upon the width of the slit, when this is not greater than the effective diameter of the "tremor disk." In the other classes of astrophysical work, almost without exception, to which reference is here made, great perfection of definition is equally unnecessary. Thus the most important objection that can be urged against the reflector has little weight in the present connection.

The relative advantages of refractors and reflectors have been so admirably summed up by Sir Howard Grubb in his memoir "On Great Telescopes of the Future,"[1] that I could hardly do better than to repeat his words. As, however, great improvements have been effected in the manufacture of glass for both lenses and specula since 1877, when this discussion was published, and as I wish to give special attention to the astrophysical side of the question, I shall deviate somewhat from Sir Howard's manner of treatment, at the same time acknowledging my obligations to his important paper.

The principal advantages of a reflector, as compared with a refractor, may be outlined as follows:

1. *Perfect freedom from chromatic aberration.*—That this is a matter of the first importance in astrophysical work can be best appreciated by those who have done spectroscopic work with large refractors. In the Lick telescope the focus for the line $H\delta$ is $81^{mm}.5$ beyond that for D_2. In the Yerkes telescope the corresponding difference is even greater, so that it has been necessary to give the collimator of the stellar spectrograph a range of motion of 150^{mm}. This dependence of focus upon wave-length seriously hampers all classes of spectroscopic work. In investigating the spectrum of a star, the Sun's chromosphere, or any other celestial object, the slit of the spectrograph must be accurately set in the focal plane of the line whose position or intensity is to be determined. Should this line happen to lie on a steep part of the color curve, the rapidly broadening spectrum on either side of it will fail to show faint lines, and incorrectly represent the intensities of brighter ones. For the purpose of

[1] *Trans. R. Soc. Dublin*, New Series, Vol. I, Memoir No. 1.

making comparisons of the relative intensities of various lines in the same spectrum, it is therefore evident that a large refractor can be used, if at all, only with great difficulty. In observing the forms of the solar chromosphere and prominences in various lines it is essential to success that the slit be placed with great exactness in the focal plane of the line in use. It is a very troublesome matter with large spectroscopes to effect this adjustment whenever it is desired to pass rapidly from one line to another. Moreover, in the case of a refractor, the magnification also depends upon the wave-length, so that photographs of prominences or of the Sun's surface taken in different lines with the spectroheliograph cannot be accurately compared without reduction to the same scale. For work with the bolometer, radiomicrometer or thermopile the single focal plane of the reflector is almost indispensable. In determinations of the colors of stars, planets, Sun-spots and similar objects made with a refractor, uncertainty often enters, because of the chromatic aberration. In photometric observations of objects having different spectra, unless the spectra themselves are compared wave-length for wave-length, the reflector will yield more trustworthy results than the refractor. A further matter of great importance is the fact that the whole field of celestial photography lies open to a reflector, which can also be used, without change of any kind, for visual observations. With the ordinary form of refractor either a separate objective must be used for each class of work, or the visual object-glass must be provided with a third correcting lens, or made with the front lens reversible to adapt it for photography. In a word, it would be hard to name a branch of astrophysical work in which the chromatic aberration of the refractor is not a serious drawback.

The interesting and valuable experiments instituted at Jena by the firm of Schott & Co. have resulted in the production of varieties of flint and crown glass with which objectives having little or no chromatic aberration have been successfully made. Unfortunately, however, the glass was found to deteriorate in a short time, a thin opaque film forming on the surface. Recently

Messrs. T. Cooke & Sons have brought out an objective composed of three lenses, which is said to be practically free from chromatic aberration, so far as the visible spectrum is concerned. I do not know that any objectives of large aperture have as yet been constructed on this plan, which of course involves increased cost of manufacture and the added loss of light by absorption and reflection in the third lens. A correcting lens placed over a visual objective to adapt it for photographic purposes is objectionable on account of the change of focus produced, the loss due to additional absorption and reflection, the inconvenience of attaching and detaching a heavy lens and cell and rebalancing the telescope, and the cost. For spectroscopic purposes a small lens placed near the focus would probably be much more satisfactory, as in this case most of the objections urged against a large lens attached to the objective are less serious. However, the field of the corrected objective would be very small, and the telescope would still not be adapted for work in the ultra-violet and infra-red. The new objective of Professor Hastings, which includes a third lens not far from the focus, shows little or no trace of secondary spectrum to the eye. But no combination of lenses yet devised can compare with a paraboloidal mirror in the capacity to unite in a single focal plane all wave-lengths from the extreme infra-red to the ultimate limit of the ultra-violet. Whatever may be the defects of the reflecting telescope, this property, so important in the estimation of the astrophysicist, must certainly be credited to it.

2. *Relatively small absorption for large apertures.*— In an object-glass composed of two lenses light is lost by reflection at four surfaces. The nature and amount of the absorption depend upon the quality of the glass used, but in all cases the most marked effect is in the ultra-violet. As a consequence it is impossible, even with a photographic objective corrected especially for this region, to photograph any considerable part of the ultra-violet spectrum of a star. The reflector, on the contrary, as Dr. Huggins' results so well attest,[1] serves admirably in photo-

[1] His spectrum of Vega reaches λ 2970.

graphing the shortest wave-lengths that penetrate our atmosphere. At the other end of the spectrum glass becomes less and less transparent for the longer waves, and beyond 2^{μ} is practically opaque. Here a reflector exercises almost no absorption and is consequently indispensable for all thermal investigations in the extreme infra-red.

With the aid of the important photometric determinations of the absorption of various kinds of optical glass recently made at Potsdam,[1] we may compare the light-grasping power of specula with that of the best modern objectives. Thanks to the firm of Schott & Co., of Jena, it was possible to select the flint and crown glass for the great Potsdam refractor from a number of samples having different coefficients of absorption. The absorption was determined for various wave-lengths between λ 6770 and λ 3900, and the samples giving the smallest absorption were chosen for the new objective of 80^{cm} aperture. With the data obtained for these chosen specimens of crown and flint glass a table was prepared, giving the absorption for various thicknesses from 4^{cm} to 40^{cm}. To extend this table so that it shall include the absorptive properties of reflecting telescopes, it remains for us to determine the light-grasping power of silvered specula.

In his memoir on "Energy and Vision"[2] Professor Langley gives the following table of the coefficients of reflection from two surfaces of silver. The wave-lengths are expressed in microns.

Wave-lengths - - -	.35	.38	.40	.45	.50	.55	.60	.65	.70	.75
Reflection, two surfaces -	.37	.54	.63	73	.79	.82	.845	.86	.875	.885

The table is stated to be "for the selective absorption of silver referred to such a lamina as is spread by the Martin process

[1] H. C. VOGEL: "Die Lichtabsorption als maassgebender Factor bei der Wahl der Dimension des Objectivs für den grossen Refractor des Potsdamer Observatoriums." *Sitzber d. K. Akad. d. W. Berlin*, 19 November, 1896, pp. 1219-1231. For a translation of this article see p. 75.

[2] *Mem. Nat. Acad. Sci.*, 5, 10.

on the front surface of the glass in its ordinary application. It is prepared from unpublished observations made by the writer with the bolometer." Unfortunately there seems to be no statement regarding the freshness of the silvered surfaces, and we are left in doubt as to the length of time they had been in use before the determinations were made. In his article on the "Telescope" in the *Encyclopædia Britannica* Dr. Gill remarks that too great reliance must not be placed on measurements of the reflective power of small, freshly prepared silvered surfaces, and adds that he "has found from experience and careful comparison that a silvered mirror of twelve inches aperture mounted as a Newtonian telescope (with a silvered plane for the small mirror), when the surfaces are in fair average condition, is equal in light-grasp to a first-rate refractor of ten inches aperture, or area for area as 2 : 3." From Professor Vogel's table (given below) we find that over 77 per cent. of the visual rays would be transmitted by a 10-inch objective of Jena glass. Disregarding the unknown difference in the absorptive coefficients of Professor Vogel's and Dr. Gill's objectives, this would indicate that after the loss suffered in two reflections and that due to the interposition of the small mirror in the path of the rays, Dr. Gill's Newtonian reflector brought to the focal plane about 53 per cent. of the visual[1] rays received by the large mirror. For the photographic rays referred to by Vogel (λ 3900 to λ 4550), Langley's results show that this coefficient would be reduced to about 48 per cent., on the assumption that the ratio of the coefficients of reflection for different wave-lengths is the same for bright as for slightly tarnished silvered surfaces. It is evident that on account of a lack of necessary data some degree of uncertainty must attend these figures. It cannot be said just how much light was cut off by the small plane mirror in Dr. Gill's reflector, as its size is not mentioned. It is safe to assume, however, that its shorter diameter was rather less than one-fifth that of the large mirror, and this ratio may be taken as a constant for all apertures. The loss of light due to the small mirror and its

[1] Taken by Vogel as lying between λ 6770 and λ 4550.

support may therefore be considered about 4 per cent. of the whole.

Since Dr. Gill's paper was written the process of silvering glass surfaces has been greatly improved by Brashear and others. In view of this fact, and also in consideration of the marked difference between his result and those of Langley (the latter having been obtained by methods which may probably be regarded as much more precise than the estimate made by Gill), we shall hardly be likely to overestimate the capacity of the instrument if we consider that 60 per cent. of the visual and 48 per cent. of the photographic rays are brought to the focal plane of a Newtonian reflector. If, as is sometimes the case, an optician is employed to keep the silvered surfaces in a highly polished condition, these coefficients may be increased to maximum values of about 78 per cent. for the visual and 61 per cent. for the photographic rays. The smaller coefficients will, however, be adopted for the purposes of the present comparison.

The following table contains the results on the transmission of light through objectives given by Professor Vogel in the paper already mentioned, together with certain additional data concerning Newtonian reflectors. It is probable that the corresponding values for Cassegrainian reflectors would differ from these in no very great degree, though Sir Howard Grubb remarks that less light is lost in this latter form of instrument.[1] In the first column is given the aperture in centimeters, which is taken as seven times the thickness of the objective, in accordance with Professor Vogel's suggestion.[2] The next five columns are reproduced without change from Professor Vogel's table. The ninth and tenth columns give the percentages of light received at the focal plane of a reflecting telescope after the loss experienced in two reflections, and that caused by the small mirror and its supports. The numbers in the seventh, eighth, eleventh, and twelfth columns are proportional to the amount of light concentrated in a stellar image by refractors and reflec-

[1] *Trans. R. Soc. Dublin*, New Series, Vol. I, Memoir No. 1, p. 2.

[2] See p. 89.

Aperture in cm	Thickness in cm	Objective: Intensity of transmitted light when incident light is unity: With respect to absorption alone: Visual rays	Objective: Intensity of transmitted light when incident light is unity: With respect to absorption alone: Rays most active chemically	Objective: Intensity of transmitted light when incident light is unity: With respect to absorption and reflection: Visual rays	Objective: Intensity of transmitted light when incident light is unity: With respect to absorption and reflection: Rays most active chemically	Objective: Light-grasping power: Visual rays	Objective: Light-grasping power: Rays most active chemically	Silvered glass speculum: Intensity of reflected light when incident light is unity (Newtonian telescope): Visual rays	Silvered glass speculum: Intensity of reflected light when incident light is unity (Newtonian telescope): Rays most active chemically	Silvered glass speculum: Light-grasping power: Visual rays	Silvered glass speculum: Light-grasping power: Rays most active chemically
28	4	0.93	0.84	0.77	0.69	6.04	5.41	0.60	0.48	4.70	3.76
42	6	0.90	0.77	0.75	0.63	13.23	11.11	0.60	0.48	10.58	8.46
56	8	0.87	0.71	0.72	0.58	22.58	18.19	0.60	0.48	18.82	15.05
70	10	0.84	0.65	0.70	0.53	34.30	25.97	0.60	0.48	29.40	23.52
84	12	0.82	0.60	0.67	0.49	47.27	34.57	0.60	0.48	42.34	33.89
98	14	0.79	0.55	0.65	0.45	62.43	43.22	0.60	0.48	57.62	46.10
112	16	0.76	0.50	0.63	0.41	79.03	51.43	0.60	0.48	75.26	60.21
126	18	0.74	0.46	0.61	0.38	96.84	60.33	0.60	0.48	95.26	76.20
140	20	0.71	0.43	0.59	0.35	115.64	68.60	0.60	0.48	117.60	94.08
154	22	0.69	0.39	0.57	0.32	135.18	75.89	0.60	0.48	142.30	113.84
168	24	0.67	0.36	0.55	0.29	155.23	81.85	0.60	0.48	169.35	135.48
182	26	0.65	0.33	0.53	0.27	175.56	89.43	0.60	0.48	198.75	159.00
196	28	0.62	0.30	0.52	0.25	199.76	96.04	0.60	0.48	230.50	184.40
210	30	0.60	0.28	0.50	0.23	220.50	101.43	0.60	0.48	264.60	211.68
224	32	0.58	0.25	0.48	0.21	240.84	105.37	0.60	0.48	301.05	240.84
238	34	0.56	0.23	0.47	0.19	266.23	107.62	0.60	0.48	339.86	271.89
252	36	0.55	0.21	0.45	0.18	285.77	114.31	0.60	0.48	381.02	304.82
266	38	0.53	0.20	0.44	0.16	311.32	113.21	0.60	0.48	424.53	339.63
280	40	0.51	0.18	0.42	0.15	329.29	117.60	0.60	0.48	470.40	376.32

tors, calculated for both the visual and the photographic rays, allowance having been made for all losses in both types of telescope. They are obtained by multiplying the square of the aperture by the percentages given in the preceding columns.

In Plate III are reproduced curves platted from the light-grasping powers given in the table. Ordinates represent light-grasping power, and abscissæ are apertures. It is evident from inspection of the curves that for apertures not exceeding 87^{cm} refractors surpass (Newtonian) reflectors in light-grasp for both visual and photographic rays. As soon as this aperture has been passed the reflector becomes the more efficient collector of the blue and violet rays, while it still gives images that are less brilliant visually. For apertures over 134^{cm} the reflector gives brighter images than the refractor in both the visual and photographic regions. It will be noticed that this aperture is much greater than the corresponding value (about 90^{cm}) deduced some years ago by Robinson in a comparison of the light-grasping power of objectives and speculum metal mirrors. I have adopted small values of the coefficients of reflection, in order to avoid the danger of exaggerating the light-grasping power of specula. The rapid relative gain of the reflector beyond this point can be best appreciated by a glance at the curve.

It is evident that if the silvered surface be kept in excellent condition the superiority of the reflector will be much greater.[1] If the comparison were extended to the infra-red or ultra-violet the refractor would be shown to be of relatively small importance for work with these rays. The percentage of light reflected by a silvered mirror increases with the wave-length. At 1^{μ} it is 96.5 (one reflection), at 2^{μ}, 97.3, and at 4^{μ} practically all the incident light is reflected. For wave-lengths of 6^{μ} and 8^{μ} the percentage of reflection has been found to be as great for old

[1] It is by no means impossible that large specula may ultimately be coated with a highly reflective film of platinum, as small surfaces are now so successfully treated in the laboratory. The experiments of M. Izarn in covering a silvered surface with an extremely thin film of bichromatized gelatine, to protect it from the air, also seem promising. (*C. R.* 118, 1314.)

and yellow silvered surfaces as for new ones with perfect polish.[1]

3. *Possible large angular aperture.*— In the case of an objective composed of two lenses it is not common to see a ratio of aperture to focal length greater than $\frac{1}{14}$, and it is practically impossible to make a good objective of this sort with a ratio greater than $\frac{1}{8}$. Specula, on the contrary, may be made with a ratio as great as $\frac{1}{4}$. Of course such specula define well only in the center of the field, but this is quite sufficient for the requirements of stellar spectroscopy and other similar work. Large angular aperture is frequently of great value in stellar and nebular photography, in stellar spectroscopic work, and in bolometric or other thermal investigations of the Moon. Mechanically a short tube is advantageous on account of its rigidity and convenience.

4. *Small cost of speculum, mounting and dome.*—A perfectly figured silvered glass speculum of thirty-six inches aperture costs rather less than $2000. The objective of the Lick telescope, of the same aperture, cost $50,000, or twenty-five times as much. For larger apertures the comparison would be even more favorable to the reflector. On account of their relatively short focal length specula can ordinarily be mounted more cheaply than objectives of the same aperture. For the same reason some saving can be effected in the cost of the dome, which, when the telescope tube is mounted with the declination axis at its center, varies nearly as the square of the focal length of the telescope used under it. In the mounting of reflectors the declination axis is usually placed nearer the mirror, so that the dome must be larger than would be the case if it were central.

5. *Possible large linear aperture.*— The largest objective hitherto constructed has an aperture of one meter. Rough disks of optical glass have, I understand, been made for telescopes of larger aperture to be mounted in Berlin and Paris. In the present state of optical glass manufacture it is perhaps possible to make an objective of 150^{cm} aperture, but both the

[1] E. F. NICHOLS, *Phys. Rev.*, 4. 303, 1897.

glassmaker and the optician would regard such an undertaking as a most formidable one, requiring at least five or six years of labor for its completion. On the other hand a speculum of 180^{cm} aperture has already been made and used by the Earl of Rosse, and the St. Gobain Plate Glass Company offered in 1896 to furnish a glass disk suitable for a speculum of 220^{cm} aperture. It is not improbable that an order for a glass speculum three meters in diameter would be accepted by the glassmaker and the optician, who might be expected to complete the work within a period of two or three years. As Sir Howard Grubb has pointed out in the memoir referred to above, large disks of speculum metal would probably be easier to obtain than glass disks of the same diameter. But the latter are generally to be preferred, on account of their comparative lightness and the ease with which they may be re-silvered without the slightest danger of affecting their figure.

The above considerations seem to show that the astrophysicist may properly consider the reflector to be an even more important part of his instrumental equipment than the refractor. For many of his investigations it is indispensable, and in most cases it offers advantages which more than offset certain other advantages enjoyed by the refractor. For direct visual observations such an instrument as the forty-inch Yerkes telescope, with its superb definition, is probably far superior to any reflector in use. It follows that an observatory which is well equipped for astrophysical research should possess both refractors and reflectors, in order that all classes of work can be prosecuted in the most advantageous manner possible.

As regards the future development of telescopes in the direction of increased light-grasping power, the reflector promises far greater gains than the refractor, especially for spectroscopic work in the so-called photographic region. Indeed, it appears from an inspection of the curves in Plate III, that an increase in the aperture of an objective beyond about 350^{cm} would be attended by no gain in the intensity of the photographic image. In the case of reflectors, on the contrary, the

light-grasping power will continue indefinitely to gain with the aperture.

The great advantages for astrophysical research offered by the *equatorial coudé* reflector, invented in its original form by my late friend Arthur Cowper Ranyard, and described by Professor Wadsworth on another page, point to this instrument as one likely to prove of great service in the future. I am glad to say that Mr. Ritchey will shortly undertake, in the optical laboratory of the Yerkes Observatory, the construction of a speculum of 150^{cm} aperture, which will be provided with a mounting of this type, and devoted exclusively to investigations in astrophysics.

Yerkes Observatory,
January 1897.

ON A NEW FORM OF MOUNTING FOR REFLECTING TELESCOPES DEVISED BY THE LATE ARTHUR COWPER RANYARD.

By F. L. O. Wadsworth.

INTRODUCTION.

In a preceding article Professor Hale has reviewed the many advantages which reflectors possess over refractors, particularly for astrophysical work. Personally, I do not think that the former can ever quite equal the performance of the latter for general visual observations, on account of the almost insurmountable difficulties in preserving the figure of the mirror under changes of temperature and changes in position; although, as I have said in a previous paper,[1] the difficulty due to the latter may be to a great extent overcome by making the specula much thicker in proportion to their diameter than has been customary heretofore, and by adopting the counterpoised support system more fully described in Mr. Ritchey's article in the present number. For measurements of position simply the reflector obviously cannot compete with the refractor, nor is there any reason why it should, since the instruments used for such measurements are never of more than what is now regarded as a very moderate size. For celestial photography the reflector is superior in the entire absence of chromatic aberration and greater light-grasping power, and some magnificent photographs, among which those of Common, Roberts, and Wilson stand preëminent, have been obtained by its use. But it is unfortunately impossible to employ it when a large field is desired; for such purposes only a photographic doublet can be used.

Since astrophysical work then offers the greatest field of usefulness for reflectors it is for such work that their mountings

[1] A Review of Professor Johnstone Stoney's article on the "Astrophysical Observatory of the Future." *Ap. J.* 4, 238.

should be primarily designed. There is no doubt that the conditions fulfilled by the cœlostat, or by the Foucault siderostat, are those most favorable for most astrophysical work, and it is on this ground that such instruments have been considered by many as more suitable than the equatorial for the use of the astrophysicist. But, as pointed out in the review already referred to, the equatorial has great advantages on the score of simplicity, ease of control, and minimum loss of light, the latter a very important consideration in the case of stellar spectroscopy. If, then, its mounting can be so designed that the observing instruments are as favorably situated as they are with a siderostat, the only possible objections to its use for all classes of work will have been removed.

The various types of reflector mountings may be divided, so far as the position of the observer or observing instrument with reference to the telescope and its mounting is concerned, into three general classes: the Newtonian, the Cassegrainian, and that class of which the recently invented *coudé* may be taken as a type, in which at least the eye end of the telescope lies in the polar axis. Of the first two forms the second is the most advantageous, because the observing instrument can be attached directly to the stiffest part of the telescope tube, *i. e.*, the support for the large mirror; but it has the disadvantage of requiring a hole through the center of the latter. The last form is the only one which realizes the conditions satisfied in the case of the siderostat; *i. e.*, of a fixed observing instrument situated in an observing room separate and distinct from the dome or space in which the telescope itself is mounted. In the case of the siderostat the axis of the observing instrument is horizontal, while in the case of the *equatorial coudé* it is inclined at an angle equal to the latitude of the place. This, however, is no great disadvantage, as in most cases it is nearly as easy to use the apparatus likely to be employed in astrophysical work in an inclined as in a horizontal position. When the rotation of the image, with respect to the observing instrument, is not detrimental, the latter may be fixed in position on a pier in the

observing room ; in other cases it may be attached to a large plate mounted on the end of the polar axis, as shown in the following figures. The great size and stiffness which can be given to this plate enables an instrument of almost any desired size and shape to be rigidly supported on the telescope. The only motion of the instrument when so mounted is one of rotation about its own axis.

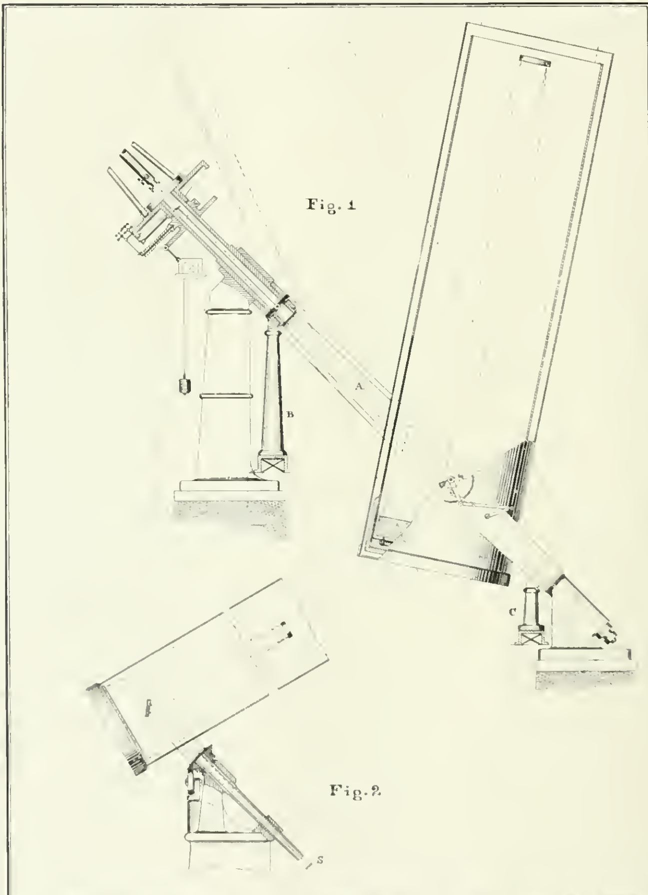
The greatest advantage of such an arrangement is the possibility of keeping the observing instrument at a constant temperature and under constant hygrometric conditions; conditions of great importance in bolometric and solar spectroscopic work, and which can never be realized in an open dome. When one reflects how much the character of an observer's work is likely to be influenced by the conditions under which he works, the minor advantages of personal comfort, and convenience of manipulation, advantages which can only be fully appreciated by those who have had an opportunity of seeing and using one of the *coudé* equatorials, are seen to be also of considerable importance.

Of the various instruments of this general type the two best known forms are the siderostatic telescope of Grubb,[1] which is simply a polar heliostat with a refracting telescope mounted in a prolongation of its polar axis and rotating with it, and the *equatorial coudé* of Loewy already alluded to.

The first has the disadvantage of having a limited range of motion in declination, the second is free from this but requires two large optical flats, each about one and one-half times the aperture of the telescope itself, one of which is in the reflector type of mounting pierced at the center by a hole of considerable size. It was probably with an idea of avoiding the expense of such a construction, while retaining all the advantages of the *coudé* mounting, that Mr. Ranyard first took up the consideration of the subject. It is the principal purpose of the present

[1] Described in the *Proc. Roy. Soc. Dublin*, **2**, 362, April 1880. In a later paper (*Trans. Roy. Soc. Dublin*, **3**, 61, April 1884), Grubb describes another form of mounting which may be called a dialyte *coudé*. No instrument of this form has, so far as I am aware, been built.

PLATE IV.



COUDÉ MOUNTINGS FOR REFLECTING TELESCOPES.

paper to decribe the beautiful form of mounting which he devised to satisfy these two conditions, and which he was prevented by his untimely death from perfecting in its minor details.

DESCRIPTION OF THE FIGURES.

Figure 1 represents in side elevation, partly in section, the original form of Ranyard's mounting, designed on as nearly as possible the original plan conceived by him and communicated to Professor Hale. The details of this mounting were never fully worked out, and had therefore to be supplied in part by the designer. Had Mr. Ranyard himself worked out the plan in full, there would probably have been less ground for criticism of many of these minor features. The polar axis of the mounting is, as will be seen, of the English form, the tube of the telescope being carried in a large closed fork, with bearings at both ends. One of the features of Ranyard's plan was to dispense with the usual dome, and replace it by a second tube parallel with and encircling the telescope tube, and moving with it, although not directly connected to it. As worked out in the present plan, this tube is carried on a fork *A* inside the main telescope fork, the declination axis being concentric with and exterior to the declination axis of the telescope itself. This fork is carried at its upper and lower ends on two pillars, *B*, *C*, which are supported on cross beams whose ends rest on two piers placed outside the two large telescope piers. These pillars, of course, prevent the complete rotation of the fork, but being narrow, allow it to swing through nearly 170°, and therefore work to within 5° of the horizon on each side.

The main feature of the Ranyard mounting is a mirror mounted in the declination axis and connected with it in such a way that it moves at half the angular speed of the latter.[1] The arrangement shown in the figure for accomplishing this is one which was designed by the writer to take the place of the usual

[1] This is also the essential feature of the dialyte *coudé* of Sir Howard Grubb, already referred to (see preceding footnote).

"minimum deviation" motion used in prism spectroscopes. It was fully described in a paper in the *Phil. Mag.* for October 1894[1]. The light from the speculum is normally reflected from a small convex mirror at the upper end of the tube, as in the ordinary Cassegrainian form, but instead of passing back through the center of the mirror, it falls upon this reflector just mentioned and by it is reflected up through the polar axis, which, as shown in the figure, is hollow. The upper end projects through the wall of the observing room, as in the *coudé* form of mounting, and to it are attached the driving-worm, the right ascension circles, and the arrangements for clamping and moving the telescope in right ascension and declination. The rods for this latter motion are carried down on one side of the opening in the axis, so as not to interfere with the cone of light.

Although the general idea of this mounting is, in my opinion, admirable, it has some few defects both of an optical and a mechanical nature, the latter of which might, as I have already said, have been avoided by Mr. Ranyard if he had carried out the design himself. Two of the greatest objections are: first, the inability to cover the entire heavens (the instrument as here designed being able to approach only to within about 25° of the pole); and second, the fact that for positions near this the line of sight is directly over the roof of the observing room and definition is likely to be seriously interfered with by the current of warm air from the latter. This last objection could be more or less done away with by making the roof of the building double and arranging for a circulation of air between the outer and the inner wall. But it will be seen that the room for this is very limited on account of the spectroscope projecting upward toward the ceiling of the room at an angle of about 45° in the present case. For lower latitudes this difficulty would of course be less.

To avoid these difficulties I have designed three modifications of the mounting, which are here presented, not because they offer a complete or fully satisfactory solution of the prob-

[1] "Fixed Arm Spectroscopes," *Phil. Mag.*, **38**, 337; *A. and A.*, **13**, December 1894.

lem, but in the hope that they may suggest to someone else a still better form.

In the first of these, shown in Fig. 2, the large speculum is mounted in a short, heavy fork at the upper end of the polar axis (as in the recent three-foot reflectors of Dr. Common and Lord Rosse). The small speculum and the movable reflector are mounted in the same manner as before, except that the latter is arranged to throw the light down the polar axis instead of up, and the driving-wheel, right ascension circle, clamps, spectroscope ring and observing instrument are all placed at the lower end of the axis instead of at the upper end, as in the preceding form. The whole polar axis is supported at its center of gravity on a single wheel, *A*, mounted on ball bearings, an arrangement which was suggested and described by the writer in the October number of *A. and A.* for 1894.[1]

It will be seen at once how much more advantageous this arrangement is as regards the position of the observing room with reference to the telescope itself. With this form it is only possible to sweep from the southern horizon to within about the same distance from the pole as in the preceding form, but the telescope may be revolved through 360° without interfering with any part of the mounting. It can be arranged to go even closer to the pole by making the fork longer, but this would not be worth while, as when it is necessary to examine objects close to the pole the reflector at the lower end of the tube can be raised slightly above its usual position and turned at right angles so as to throw the light along the top of the declination axis. The spectroscope or other observing instrument can then be mounted directly on the latter, as shown in Fig. 5.

With this form a greater length of flat is necessary for objects at or near the zenith, but not so great a length for objects near the horizon as in Ranyard's form. Since the major-

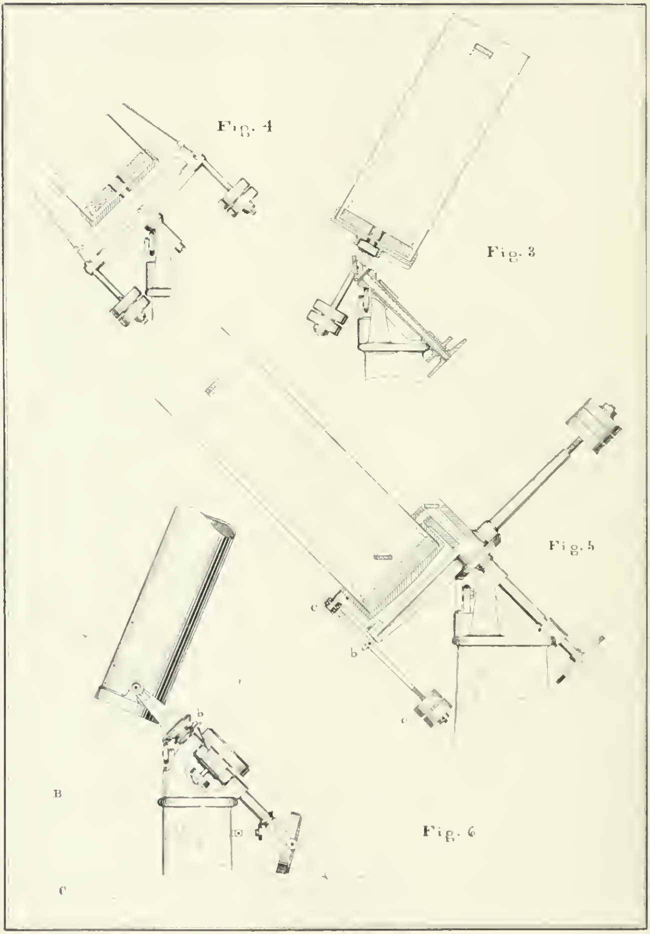
[1] I have since learned that this same device was previously used by the Repsolds in the mounting of the Pulkowa refractor. It is highly commended by Dr. Gill in the *Enc. Brit.* (see 9th ed. 22).

ity of work is done by preference on objects near the zenith, the latter has the advantage in this respect. But aside from the increased length of the reflecting surface rendered necessary, the high angle of incidence is an advantage in diminishing the effect of errors of the flat and in diminishing the loss of light by this reflection. Moreover, the distance from the flat to the focus can, as will readily be seen, be made much less than when the light is sent up the axis, and a shorter equivalent length of focus therefore obtained.

To avoid the necessity for changing the arrangement of the instrument for objects near the pole another modification of the mounting shown in Fig. 3 was devised. The arrangement is very similar to the Cassegrainian mounting except for the introduction of the reflector in the declination axis as already described. The light from the convex mirror passes through the center of the large speculum and falls on the flat, which is in this case placed behind the speculum. The form of the mounting necessary to carry out this idea is somewhat similar to the old saddle-back mounting, but is much neater in general appearance, as the counterpoise weights and telescope tube are in one straight line. The fork on which the declination axis is supported is attached to the lower end of the telescope tube instead of to the upper end of the polar axis as in the preceding form, and can, as will be readily seen from Figs. 3 and 4 (the latter representing the instrument pointing directly at the pole), be made much shorter than before, while still allowing the instrument to sweep over the entire heavens. Another advantage of this reversed arrangement is that the center of gravity of the telescope, which when the instrument is in balance lies at the intersection of the declination and polar axes, is thus brought nearer the upper end of the latter.

In all the instruments so far described the flat has had to be unusually long for certain positions of the instrument, and in the case of the first two forms it has only been possible to cover a portion of the sky without rearrangement of some part of the instrument. The form next to be described avoids all of these

PLATE V.



COUDÉ MOUNTINGS FOR REFLECTING TELESCOPES.

difficulties, but only at the expense of an additional reflection. It has however the advantage of requiring no relative motion between the flat in the declination axis and the telescope tube. In measurements of position this might become of considerable importance, although if the link motion already described is used for connecting the flat with the declination axis, there is much less chance of error than in the ordinary minimum deviation motions. In this form, which is shown in Fig. 5, one reflector is arranged as before in the declination axis, but is turned at 90° to its former position so as to reflect the rays along this axis instead of along the polar axis. The second reflector is then placed at the intersection of the polar and declination axes, in such a position as to reflect the light down the latter. These two small reflectors are rigidly fixed in position with respect to the declination and polar axes respectively, and as will readily be seen, bear the same relation to each other as do the two large reflectors in the *coudé* equatorials. If desired for any particular purpose the second reflector may be removed and the spectroscope or other observing instrument mounted directly in the declination axis, as shown by the dotted lines in the figure. The arrangement for relieving the friction on the polar axis is the same as in the preceding two forms, but on account of the overhanging of the fork which carries the outer end of the declination axis in this form, a special device has been introduced for transferring about 90 per cent. of pressure from this point to another point much nearer the end of the polar axis. This is accomplished by means of a lever, which is pivoted on a ball and socket or gimbal joint at *b* and has at its upper end a ring of U shaped inner section, *c*, which surrounds the declination axis. Between each arm of the U and a steel flanged collar on the declination axis is a row of balls. On the other end of the lever is placed a weight *d* of such mass that its moment about *a* is equal to the moment of about 45 per cent. of the mass of the telescope, acting at *c*.

The remaining 5 per cent. of the pressure on the outer fork arm is easily supported by the latter even when it is compara-

tively light without danger of flexure.[1] The inner support of the declination axis is a prolongation of the polar axis itself, and is in consequence so stiff and rigid that there is no necessity of relieving the pressure upon it so far as any danger of flexure is concerned. By placing the arm which carries the counterpoise in right ascension in line with the base of the fork, the center of mass of the telescope, fork, and counterpoise weights is brought so near the end of the polar axis. that only a slight weight on the end of that axis is sufficient to bring the center of gravity of the whole revolving system directly over the friction wheel under the upper end of the polar axis. Ordinarily this weight would be furnished by the spectroscope or observing instrument attached to the lower end, so that no dead weight is really necessary.

It has not been thought necessary to show in these latter three figures the details of the slow motions, circles, etc. Their arrangement is perfectly obvious.

In this connection it may also be interesting to show a form of mounting which has suggested itself as especially adapted for astrophysical observatories, in which three separate and distinct instruments are carried on the same mounting without interfering in any way with each other. This arrangement is shown in Fig. 6. It consists of a large reflector mounted in the same way as in Fig. 5, except that the second reflector is turned through 180° so as to reflect the light up the axis instead of down. As the telescope itself is mounted to one side of the polar axis, a small observing room into which the spectroscope may project, may be built in the prolongation of this axis without interfering with the motion of the telescope, even when the latter is pointed toward the pole. The polar axis of the reflector mounting is hollow, as before, and through it projects a second axis which carries at its lower end the fork of a polar heliostat, which may be supported as shown, by a second independent friction

[1] This same method of removing the pressure from the outer ends of the fork might be used with advantage in the case of the mounting shown in Fig. 2. The fork arms could then be made much lighter than has been possible in previous mountings of this kind.

wheel placed at the center of gravity of the fork and its axis, so as to entirely relieve the friction between the two axes. The two axes may be clamped together so as to revolve as one when desired, and since one may be moved into any position with reference to the other, two entirely separate objects can be followed at the same time. Between the two forks in which the polar axis of the telescope is mounted is a sleeve having its bearing on the moving axis of the reflector, and carrying a cœlostat mirror. This is normally free on the telescope axis, but may be connected with it by gears, *b*, so as to be made to revolve with it at half the angular speed. This cœlostat mirror may then be set on any third object, and when connected as just described to the telescope axis, will of course follow this object. We have, therefore, the first instrument, viz., the reflector, with which observations are carried on on a floor *A*; a second instrument, the polar heliostat (which may if desired be replaced by any form of siderostat), with which observations are carried on at a level *C*; and the third instrument, the cœlostat, with which observations are carried on at the intermediate level *B*, each working entirely independently of the others. In the case of very large instruments the cost of the mounting, as is well known, is more than half the cost of the whole instrument, and the combination of three instruments on one mounting would therefore effect a very considerable saving in the aggregate cost of the whole combination, besides utilizing space in the observing dome to much better advantage than is usually done.

The large cost of the usual form of revolving dome compared with the cost of the instrument for whose protection it is designed raises again the question as to whether some cheaper and at the same time efficient arrangement cannot be invented to take its place. With the original *coudé* forms this dome is not necessary, or rather its place may be taken by a simple form of wind screen to insure stability in high winds.

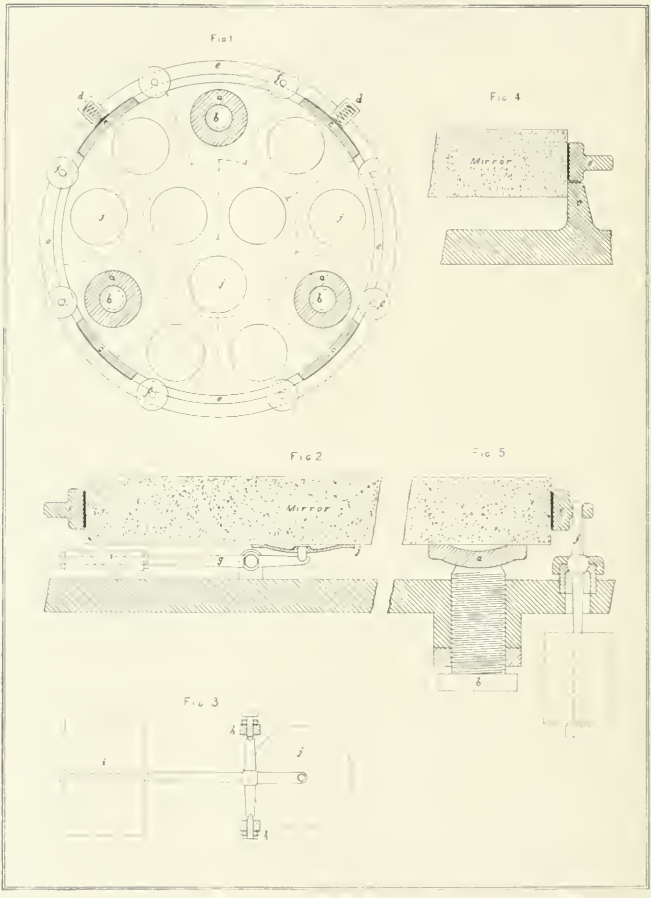
In Ranyard's form, however, something more is necessary, and his plan of using an outer protecting tube instead of a large

dome seems a step in the right direction. There are, however, great mechanical difficulties to be overcome, and the plan of mounting this tube shown in Plate IV, must be regarded as only a crude attempt to illustrate how the idea may be carried out. I have under consideration a number of other plans of protection both for these forms and for the ordinary refractor mountings (the general idea of one of these plans was sketched in a recent number of this journal),[1] but none of them have been developed sufficiently to warrant description at the present time.

YERKES OBSERVATORY,
January 1897.

[1] *Ap. J.* 4, 240.

PLATE VI.



SUPPORT SYSTEM FOR LARGE SPECULA.

A SUPPORT SYSTEM FOR LARGE SPECULA.

By G. W. Ritchey.

In properly supporting a large telescope mirror in its cell, to secure at once freedom from flexure and great stability of position of the mirror, a degree of care and refinement is demanded which is not necessary, to the same extent, at least, in the case of an objective; for, as is well known, flexure of a telescope mirror is directly injurious to the sharpness of the focal image, there being no inherent partial correction or compensation such as occurs in case of flexure of an objective. And there is another somewhat similar consideration: a tilting of the mirror in its cell directly affects the position of the focal image, while with an objective such a change of position is compensated for as in the case of flexure. When the mirror or objective moves in its own plane, the effect on the position of the image is direct, and is, in general, the same in both.

The beautiful mirror-support systems devised by Lassell, Grubb, Common, and others, while probably leaving little to be desired so far as supporting the mirror without flexure is concerned, certainly do not give the very great stability of position which is desirable in view of the considerations named above, and in view, also, of the fact that the most promising lines of work for the reflector are in the direction of photography and spectroscopy, in which long exposures are necessary, with the utmost attainable precision in pointing and following.

The mirror support system described below was devised for the purpose of affording a "flotation" support which would be not inferior to the best hitherto in use, and at the same time of affording a very high degree of stability of position of the mirror in its cell. It was designed by the writer many years ago, but has not hitherto been published, though the detail drawings were shown to Professor Hale in 1891.

The back support.— Let us consider the mirror to be divided into twelve imaginary segments of equal weight (see Fig. 1, Plate VI). The back of the mirror rests, primarily, upon three strong hardened steel plates, represented by the three shaded circles *a* Fig. 1, and at *a* Fig. 5, the center of each plate being directly back of the center of weight of the corresponding segment. The upper surface of each of these plates is ground to fit the back of the mirror; the lower surface is slightly convex and is ground to fit a corresponding concave in the upper end of each of the three large adjusting screws for adjusting the optical axis of the mirror, these adjusting screws projecting slightly through the massive casting which forms the mirror cell. This is shown in Fig. 5. It will be noticed that these three plates are near the edge of the mirror, in the outer ring of segments, and that the base of support is therefore much larger than in the support systems mentioned above. It is evident that by properly designing these steel plates and the adjusting screws which support them, we can fix with great stability the plane of the mirror which rests directly upon them, their being no *building out* from these three primary points of support — no intermediate levers as in the older systems.

Now the weight of the remaining nine segments of the mirror is just balanced by means of nine weighted levers, entirely independent of each other, which lie in a plane parallel to the back of the mirror. One of these levers is shown at *g* Fig. 2, and in plan in Fig. 3. These levers are suspended between pivots screwed through lugs projecting from the cell. The small cone-bearings *h* Fig. 3, are carefully made to reduce friction. The long arms of these levers carry adjustable lead weights (*i*, Figs. 2 and 3) which, in order to occupy as little space as possible perpendicular to the plane of mirror, are in the form of plates instead of cylinders; the short arms of the levers are thus made to press against the back of the corresponding segments through the medium of light plates, represented by the unshaded circles in Fig. 1 and at *j*, Fig. 2.

Let us suppose that the mirror weighs 120 pounds. With

the cell in a horizontal position the lead weight on each lever would be adjusted by means of a standard weight of ten pounds placed upon the plate on the short arm. This adjustment being completed, if the mirror be now laid upon the support system the nine levers will, of course, carry ninety pounds of the weight of the mirror, and the remaining thirty pounds will be distributed equally upon the three plates on the upper ends of the adjusting screws. Thus each of the twelve segments of the mirror, weighing ten pounds apiece, will be balanced, independently, by a pressure of ten pounds exerted directly against it from beneath. Now suppose that the edge support of the mirror, which will be described below, be introduced and the entire system inclined in any direction and at any angle. It is evident that, so far as the back support is concerned, there will still be a perfect balance maintained; and this whether the levers lie in such a direction that the vertical planes through the length of the levers are parallel to the vertical plane through the axis of the telescope tube, or not.

The edge-support.—The connection between the back-support and edge-support is so intimate that any inefficiency in the latter will effect injuriously the operation of the former, however perfect that may be in itself. In an equatorially mounted mirror, different points of the edge of the mirror become successively lowest, of course, as the position of the telescope is changed. In the flexible band and cushioned edge-support so much used in England, the heavy mirror therefore necessarily changes its position, laterally, with respect to its cell, in taking its bearing down against the edge-support; thus not only is stability lost, but this tendency to lateral shift must impair the freedom of operation of the back-support system.

In the plan under consideration four metal arcs are used (c, c, c', c', Fig. 1) for the purpose of fixing the position of the mirror laterally; two adjacent arcs are cast directly on the cell, as at c, Fig. 4; the other two, diametrically opposite these, exert a slight pressure against the edge of the mirror, by means of weak springs, for the purpose of holding it against the stationary

arcs; this pressure need amount to only a very small percentage of the weight of the mirror, for all of the lateral pressure due to the weight of the mirror, when in oblique positions, is carried by a stiff metal ring (*e*, Figs. 1 and 5) which encircles the edge of the mirror, and fits it loosely, a thin band of hard leather being inserted between the ring and glass. This ring is suspended by three short wires from the telescope tube above, so that if the mirror were removed the ring could swing freely in its own plane. This ring is pressed against the edge of the mirror, when the latter is inclined, by a series of eight short weighted levers (*f*, Figs. 1 and 5) which hang perpendicularly to the plane of the ring. These levers are suspended from the cell-plate behind the ring by means of ball-and-socket joints, or preferably, to reduce friction, on pivoted universal joints. The ends of the short upper arms of these levers fit loosely into holes in the ring; the lower ends carry lead weights, the adjustment of which, so that the eight levers will just balance the combined weight of the mirror and edge ring, is effected in a manner very similar to that described in the case of the levers for back support.

Remarks.— It will be noticed that the edge-support and back-support systems work together well. The latter is always free from the great constraint and friction which any tendency to lateral shift of the mirror would introduce.

The number of segments independently balanced by the back-support system may of course be increased in the case of very large or thin mirrors. An incidental advantage which occurs when this is done is that the base of stable support afforded by the three plates on the adjusting screws, will be still larger, compared with the size of the mirror, than when twelve segments are used.

All of the levers used in the back-support can be exactly alike, as can also the eight levers used in the edge-support; this is advantageous in point of simplicity and economy.

Since it is desirable that the mirror cell be a massive casting, to insure great rigidity, care has been taken, in designing it, to afford ample ventilation at the back of the mirror, so that front

and back of the latter shall be similarly exposed to temperature changes. The back of the mirror, as well as the face, is polished and silvered, in order that the two surfaces shall be similarly affected by such changes.

It is evident that the more perfect the "flotation" effect afforded by a support system, the thinner can the mirror be, in proportion to its diameter. The difficulties encountered in making very *thick* disks of glass which are homogeneous and thoroughly annealed, are so great that the problem of properly supporting comparatively thin mirrors becomes a most important one in the case of very large apertures.

YERKES OBSERVATORY,
January 1897.

Minor Contributions and Notes.

NOTE ON THE RANYARD MOUNTING FOR REFLECTING TELESCOPES.

In connection with Professor Wadsworth's description of a novel form of mounting for a reflecting telescope, devised by the late Arthur Cowper Ranyard, it may not be out of place to narrate here certain incidents connected with the last year of Mr. Ranyard's life which are intimately related to the subject of the paper.

In the autumn of 1893, while on the way through England to the Continent, Mr. Ranyard's kindly persuasions caused me to deviate from a direct path to Berlin in order to spend a few days with him in Paris. At the Paris Observatory we employed most of our time in examining the lunar and stellar photographs of the MM. Henry, the photographs of stellar spectra obtained by M. Deslandres with the remodelled reflector of Eichens, and the large scale photographs of the Moon, then but recently taken with the *equatorial coudé* by M. Loewy. The instruments themselves received no small share of our attention, and we were both particularly struck with the *equatorial coudé*, which in spite of its great size and weight is yet so perfectly within the control of the observer in his fixed position at the eyepiece.

During the following winter, which we passed in Berlin, I heard frequently from Mr. Ranyard, and it was planned that he should join our expedition to Mount Etna in the spring of 1894. This, unfortunately, his failing health did not permit him to do, but early in March, just before our departure for Italy, he paid us a visit of a few days in Berlin. He was naturally most anxious to see the Astrophysical Observatory at Potsdam, and we were fortunate in being able to spend some hours there with Professors Vogel and Scheiner. Naturally the discussion was confined for the most part to the beautiful photographs of stellar spectra obtained with the spectrograph attached to the 12-inch refractor. A careful examination of the original negatives with a microscope, coupled with a minute explanation of the details by Professor Vogel, produced a great impression upon Mr. Ranyard, and undoubtedly had much to do with his subsequent decision to take up

stellar spectroscopic work with a reflector. While thoroughly familiar with spectroscopic methods, and alive to the remarkable progress made in stellar spectroscopy since the pressure of duties at Lincoln's Inn and the demands of editorial work had diminished his activity as an investigator, his confidence in the high degree of accuracy recently attained in determinations of motion in the line of sight needed just such strengthening as the visit to Potsdam brought to it. The enthusiastic belief in the modern methods of stellar spectroscopy thus aroused was checked only by his death. It entered into a resolution formed when his illness was in its earlier stages, to remove from London in order to devote the major part of his time to astrophysical research. And it probably led him to devote the valuable form of mounting for a reflecting telescope described by Professor Wadsworth on another page. G. E. H.

A NOTE ON A NEW FORM OF FLUID PRISM.

I HAVE just received a letter from Lord Rayleigh in which he is kind enough to point out that the idea of making a fluid prism with a free liquid surface was suggested long ago by Brewster in his Treatise on Optics (§53, 455.) I am not surprised to hear that I have been anticipated, for, as I remarked in my paper, it would have been indeed surprising had so simple an idea not previously suggested itself to someone else. As however I had never seen it described, I thought it worth while to publish the description of it that I did. As there is unfortunately no copy of Brewster's work either in my own library or in that of the Observatory and as the nearest reference library is nearly eighty miles away, I have not yet had an opportunity to consult the reference myself and so am not sure but what Brewster suggested some better arrangement than mine. It is quite probable that he did, but even in the form in which I used it, its performance was most promising, and I think I may say as Poynting did with reference to the parallel plate micrometer: "Now that I have no claim to its invention I may perhaps fairly express the opinion that the instrument is of great value." F. L. O. WADSWORTH.

REVIEWS.

Observatory Atlas of the Moon. Lick Observatory. Published by the gift of W. W. LAW, ESQ., of New York City.

THE first sheet of an observatory atlas of the Moon, a work which when complete, will consist of sixty or more plates, with index map, etc., has been distributed by the Lick Observatory. The scale of this important photographic map is the same as that of Beer and Mädler's chart (three Paris feet or $38^{in}.36$ to the Moon's diameter), and half that of Schmidt's chart. The plate just published shows the terminator, with the Moon near the third quarter, from the south pole to about 30° south latitude. It is reproduced from the original negative by a gelatine process, which has the advantage of giving satisfactory results at a comparatively small expense; and in a work like this, requiring more than sixty different plates for its completion, the cost of the reproductions is a consideration of no small importance.

It is interesting to compare this atlas with the one just issued by the Paris Observatory, an account of which was given in the last number of the ASTROPHYSICAL JOURNAL. If we regard the plates in these two atlases as pictures, the advantage is altogether with the Paris heliogravures; they are larger, more brilliant, more impressive. But pictorial effect is evidently no just criterion of scientific value, and if we regard the atlases from the latter standpoint, we see that each has certain advantages of its own. In the Paris photographs the enlargement has, perhaps, been pushed beyond the limit of usefulness, and it would seem that everything which appears on the plates would be shown equally well if the scale were only half as great. If this is so, the impressive appearance above referred to has been gained at the expense of handiness. Further, an examination of the Lick Observatory plate shows that brilliancy of effect has been deliberately sacrificed to secure other and more solid advantages. The printing has been carried so far that details appear in even the highest lights, with the result that, while much is shown that otherwise would have been lost in the process of reproduction, scarcely any pure white is found in the picture, and a general flatness of effect is produced. Each atlas has,

therefore, its own special value. The Paris atlas will be eminently useful for consultation in its place on the library table; the Lick Observatory atlas will find its chief use in the hand of the observer at the telescope.

No information is furnished with the plates as to the manner in which the Lick negatives are obtained, although all necessary particulars will doubtless be given with the text of the completed atlas. Professor Holden has given some details of the process in a review[1] of the Paris atlas, from which it appears that the image is directly enlarged in the telescope to a diameter of twenty-six inches, and the resulting negative is then further enlarged to the scale of the plates. The difficulties attending the first part of the process are partly obviated by the use of specially sensitive dry plates, which allow the exposure times to be reduced to ten or even to five seconds. The chief advantage of this method over that of enlarging a negative obtained at the focus is, that the coarseness of grain of the dry plate becomes relatively less important. In the Paris photographs the grain is quite conspicuous, as one would expect from the great enlargement of the original negative. A fine grain which is noticeable in the Lick Observatory plates is not, according to Professor Holden, derived from the original negative, but is introduced by the process of reproduction. It is not stated with what aperture the direct enlargements were made.

It seems to the reviewer that it would be worth while (if the attempt has not already been made) to try the old wet plate process with the modern great refractors, or at least slow and fine-grained plates such as are used for lantern transparencies. When negatives of the Moon are made on quick plates in the focus of a great telescope, the best results appear to be obtained by greatly reducing the aperture; at least this is true for the Lick telescope, which gives the sharpest definition when the aperture is stopped down to about eight inches.[2] There is little doubt that this improvement is mainly owing to the fact that with the ordinary ratio of aperture to focal length, the resolution of a photographic telescope is determined by the grain of the plate, rather than by the aperture of the objective. The telescope is unnecessarily good for the plate. Hence the aperture can be reduced without injury to the definition, and an improvement will result if the reduction is attended by gain in other directions, as for example in the diminution

[1] *Pub. A. S. P.*, No. 53, 8, 319 324, 1896.

[2] *Publications of the Lick Observatory* 3, 3.

of the effects of chromatic aberration and atmospheric disturbance. Supposing atmospheric difficulties to be avoided by choosing only the finest nights for observation, should we not expect to gain in definition by using fine-grained plates, with an aperture large enough to compensate for their greater slowness by increased brightness of the image? K.

Die Schwankungen im Wasserdampfgehalte der Atmosphäre auf Grund spectroskopischer Untersuchungen. TH. ARENDT. *Wied. Ann.*, **58**, 171–204, 1896.

IN this paper the author, a member of the staff of the Prussian Meteorological Observatory at Potsdam, gives an account of his spectroscopic investigation of the variations in the amount of aqueous vapor in the atmosphere during the latter part of the summer of 1895.

The method employed was that of estimating the intensity of the aqueous vapor lines in terms of the intensity of nearly equal metallic lines in neighboring parts of the spectrum, in a manner quite analogous to Argelander's method in stellar photometry. The third-order spectrum of a plane Rowland grating was used in connection with the large spectrometer of the Potsdam Astrophysical Observatory.

Six vapor lines were selected for observation from each of two groups of atmospheric lines, the one near C and the other near D, and respectively ten and fourteen metallic comparison lines were carefully estimated until a scale, having in the two cases ranges of 22 and 29 intensity "steps," was established. The intensity of the atmospheric lines could then at any time be estimated in steps by comparison with the metallic lines of most nearly equal intensity.

The two variable groups were treated separately in the reductions, the mean of the estimates of intensity of the six lines of each group being taken to represent the absorption in each group at the time of the observation; for which the zenith distance of the Sun and the length of path of the rays were also calculated.

In order to draw inferences as to the amount of aqueous vapor present in the air, it became necessary to reduce the observations to a uniform length of path, as they had been made at altitudes of the Sun ranging from 54° to 22°. A standard length of path of 1.50 (that for the zenith being unity) was adopted, corresponding to a zenith distance of the Sun of 48°, and corrections were applied to the observed inten-

sities to reduce them to this standard. To calculate the corrections it was necessary to test the law of increase of intensity of the lines with increase of path, which from observations of Cornu and of Müller was expected to be that of direct proportionality. This was fully confirmed by series of observations on the same day at different solar altitudes.

When the intensity of the absorption is thus reduced, and compared with the absolute humidity for each date, a close accordance is found. The author rationally considers the series of observations still too brief to justify conclusions as to the meteorological conditions in inaccessible layers of the atmosphere. He confirms the results repeatedly obtained elsewhere that the transparency of the air is greatly affected by the amount of aqueous vapor present.

As to the practical use of the method in weather prediction, Dr. Arendt gives a decidedly negative opinion. It does not follow that all methods of studying the rain-band are without value in forecasting, but it is perhaps a necessary defect of a method which always requires the spectroscope to be directed toward the Sun. For most purposes it would be desirable to measure the absorption in all azimuths, and at much lower altitudes than is possible when the Sun must be directly observed; since changes in the rain-band are of course much more pronounced when the path of the rays is long, as at altitudes of 5° or 10°. For use in connection with short forecasts, the instrument devised by C. S. Cook (*Science*, **2**, 488–491, 1883; *Am. Jour.* (3), **39**, 258–268, 1890) would seem much more suitable (to one who has used it).

The procedure adopted by Dr. Arendt appears as suitable, and the results obtained as satisfactory, as those described by Jewell in a late number of this JOURNAL (**4**, 324–342), where a photographed scale was employed for comparisons of intensity. The accuracy of Argelander's method is sufficiently established in stellar photometry to warrant its extension to spectrum lines; the exercise of judgment being required in comparisons with an artificial scale quite as much as in direct estimates.

The testimony of both observers now referred to makes it evident that there is much to be improved in methods of meteorological spectroscopy, but the papers of Arendt and Jewell may be considered as reports of progress.

E. B. F.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

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PLATE VII.

THE YERKES OBSERVATORY, AS SEEN FROM LAKE GENEVA.

FEBRUARY 1897.

THE

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RÉSUMÉ OF SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE DURING THE SECOND HALF OF 1896.

By P. Tacchini.

I give below a résumé of the solar observations made at the Royal Observatory of the Roman College during the second half of 1896. The following results have been obtained for the spots and faculæ:

1896	Number of days of observation	Relative Frequency		Relative Size		Number of spot groups per day
		of spots	of days without spots	of spots	of faculæ	
July	30	11.24	0.00	42.1	86.8	3.0
August	27	6.34	0.11	20.8	72.4	1.8
September	29	24.59	0.00	63.4	64.0	3.4
October	21	11.53	0.05	29.1	123.5	2.4
November	17	15.30	0.00	79.9	71.5	4.0
December	17	12.18	0.00	45.8	77.1	2.9

A point worthy of notice in this series of observations is the secondary minimum for the spots in the month of August, followed by a maximum, due largely to the appearance of the magnificent group visible from the 10th to the 22d of September. On September 16 this group was formed of sixteen spots and twenty-seven pores, and had an extent of 6′ parallel to the equator.

For the prominences we have obtained the following results:

1896	Number of days of observation	Prominences		
		Mean number	Mean height	Mean extent
July . .	30	4.26	36 .2	1 .8
August	24	4.00	34 .6	1 .1
September	26	3.77	34 .9	1 .2
October . . .	14	6.93	38 .7	1 .6
November	9	5.56	39 .9	1 .9
December .	9	3.78	39 .4	2 .0

The weather was very unfavorable for spectroscopic observations during the fourth quarter, and especially during the last two months of the year. Even in August, when the weather is ordinarily most favorable, we frequently had a bad sky.

The minimum for the prominences occurred at the time of the spot maximum, and in comparison with the preceding series it may be said that the phenomena of the prominences have remained almost stationary.

Following are the results for the distribution in latitude of the different solar phenomena, calculated for each quarter:

1896 Latitude	Prominences				Faculæ				Spots			
	Third quarter		Fourth quarter		Third quarter		Fourth quarter		Third quarter		Fourth quarter	
90 + 80	0.000		0.010									
80 + 70	0.000		0.010									
70 + 60	0.000		0.005									
60 + 50	0.042		0.047									
50 + 40	0.099	0.472	0.068	0.364	0.000							
40 + 30	0.127		0.073		0.000		0.013					
30 + 20	0.105		0.068		0.047	0.244	0.038	0.298	0.037			
20 + 10	0.062		0.052		0.090		0.120		0.182	0.345	0.075	0.200
10 + 0	0.034		0.031		0.107		0.127		0.126		0.125	
0 — 10	0.082		0.094		0.140		0.196		0.182		0.200	0.800
10 — 20	0.130		0.120		0.276		0.253	0.702	0.382	0.655	0.000	
20 — 30	0.141		0.162		0.223	0.756	0.190		0.021			
30 — 40	0.093		0.099		0.094		0.063					
40 — 50	0.065	0.528	0.099	0.636	0.017							
50 — 60	0.011		0.031									
60 — 70	0.006		0.016									
70 — 80	0.000		0.010									
80 — 90	0.000		0.005									

The frequency of each class of phenomena has increased in the southern zones. The prominences have been quite numerous from the equator to $\pm 50°$, as in the preceding six months. The faculæ have been confined within latitudes $\pm 40°$, and the spots within $\pm 30°$ during the third quarter and $\pm 20°$ during the fourth quarter. It must also be remarked that during the six months prominences have been seen in every zone, and very near to the poles.

The great extension in latitude and the wide zones of frequency of the prominences permit us to consider the solar corona to be more closely related to the prominences than to other solar phenomena. It follows that according to our observations the corona at the time of the last eclipse should have appeared low from the polar regions to the parallels of 60°, and clearly marked and much more extended from the equator up to $\pm 60°$, just as it is shown in such photographs and drawings as I have seen up to the present time. It therefore seems to me safe to say that the variations of the solar corona should be in accord with those of the prominences.

ROME, January 30, 1897.

OXYGEN IN THE SUN.

By Arthur Schuster.

In an important communication printed in the current number of the Astrophysical Journal (December 1896) Professors Runge and Paschen give strong evidence that one of the triplets of the spectrum, which I have called the "compound line spectrum" of oxygen, appears in the Sun. The question whether the lines of this spectrum coincide with dark solar lines was discussed by myself nearly twenty years ago (*Nature*, Dec. 20, 1877), and I then gave what at that time seemed to me to be the evidence in favor of its presence. But the resolving power used was inadequate, for the triplets were observed as single, their triplet nature being discovered later by Piazzi Smyth. As a matter of history I may quote the remarks made by this eminent spectroscopist on the solar coincidences with the compound line spectrum of oxygen. After referring to my own work on the subject he writes (*Trans. R. Soc. Edinburgh*, Vol. XXX, Part I) "In apparently the very place of the three fainter of the above described divided triplets there is a close double of peculiarly thin Fraunhofer lines depicted by Professor Ångström in his normal solar spectrum map; and in the place of the brightest of them, viz., Schuster's orange line, there is a triple of the same kind of ultra thin lines; and not one member of all those four groups has been claimed for any known element by the great Swedish physicist. Yet I am by no means satisfied that the degree of correspondence is conclusive; and can only hope that those who have the means will positively confront the new oxygen triples with the Sun itself, and inform us what they find." Nothing further was done on the subject until Runge and Paschen took the matter up, and gave additional weight to the probability of the presence of oxygen in the Sun. The coincidence they point out does not refer to any of the triplets which Piazzi Smyth mentions in the above quotation, but to one which lies in the red. The reason why I have referred to my

own contribution to the subject is not that I attach any weight to it (on the contrary, it is quite clear now that I could not with the dispersion I used institute any satisfactory comparison) but that in my letter to *Nature* to which reference has been made, I drew attention to one circumstance which seems to me to deserve the serious attention of those who have the necessary instruments at their disposal. This is the fact that Young gives in his list of chromospheric lines, observed at a height of 8300 feet, two lines having wave-lengths of 5435.4 and 5329.1, in Ångström's scale, the frequency of the first being given as 5, that of the second as 6. These lines are sufficiently near two of the oxygen triplets to make it desirable to ascertain their wave-lengths more closely, and especially to determine whether the chromospheric lines are not in reality close triplets. Without knowing that Runge and Paschen were engaged on this question I recently examined the oxygen spectrum with a Rowland concave grating in order to determine the wave-lengths more accurately. The wave-lengths for the more refrangible of the above triplets which I have obtained are on Rowland's scale

5330·793 5329·827 5329·293

I do not however wish to consider these numbers as final, as they are only the result of one series of measurements. There are two lines on Rowland's list (5329·329, 5329·975), which are very near the two strongest components of the triplet, but they are assigned to chromium, and if the oxygen lines are really in the Sun they would probably be hidden by these chromium lines. Rowland also gives a weak line corresponding to the weakest and least refrangible component of the triplet, 5330.748. So far then as this triplet is concerned the solar coincidence can neither be affirmed nor denied, but if the chromospheric line is really triple and in agreement with the members given, the presence of oxygen in the Sun would be proved beyond doubt. In view of the great importance of this subject in all problems referring to the constitution of the Sun, I may perhaps be allowed to urge the full investigation of this question on those who are working under sufficiently pure atmospheric conditions.

MANCHESTER, January 31, 1897.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

I. SELECTION OF THE SITE.

By GEORGE E. HALE.

INTRODUCTION.

WHEN The University of Chicago commenced its work in the autumn of 1892 it was but poorly equipped for investigation in astronomy and astrophysics. The twelve-inch telescope and other apparatus of the Kenwood Observatory, though admirably adapted for certain kinds of astrophysical research, were useless in many fields of investigation which The University desired to enter. It was consequently felt that an effort should be made to provide The University with an observatory of the first class, equipped with facilities for observational and experimental work in all branches of astronomy and astrophysics.

In September, 1892, Mr. Charles T. Yerkes of Chicago, a gentleman widely known for his liberal encouragement of art, offered to purchase for The University of Chicago a pair of disks of optical glass 42 inches in diameter, by Mantois of Paris, which were then in the workshop of Mr. Alvan G. Clark at Cambridgeport, Mass. An opportunity to purchase such large and perfect disks is naturally a most exceptional one, arising in this instance from certain complications, which prevented an institution in southern California from carrying out its plan of establishing a large telescope in the vicinity of Pasadena. Mr. Yerkes' generous offer to The University, which included the assumption of the entire cost of building an equatorial refractor of forty inches aperture and housing it in a suitable observatory, was received with great satisfaction and accepted immediately. After the object-glass had been ordered from Mr. Clark, and a contract for the equatorial mounting had been made with Messrs. Warner and Swasey, the question of selecting a suitable site for the Observatory was taken up for consideration.

CONSIDERATIONS REGARDING THE CHOICE OF A SITE FOR AN ASTRONOMICAL OBSERVATORY.

In choosing an observatory site both general and special hindrances to observational work must be given consideration. In general, it is desirable to avoid localities where the mean annual cloudiness is high, or where much difficulty is likely to be experienced from wind, dust, or dew. The special requirements of the particular observations comprised in the Observatory's plan of work should next receive attention. In the following table, which has been prepared with the assistance of Professors Barnard and Wadsworth, I have indicated by the letters *A*, *B*, and *C* the approximate degree of excellence required in the "seeing," transparency of the atmosphere, blackness of the sky, and steadiness of the instruments, for various classes of astronomical and astrophysical work. In each case *A* indicates that the particular condition to which it refers should be the very best possible; *B*, that it should be fair to good; *C*, that it need be only fair, or may even be distinctly bad without materially affecting the quality of the work. Ordinarily the letters in the fourth column refer to the required degree of steadiness of the telescope or principal observing instrument. When a second accented letter is given it refers to the conditions required for a galvanometer or other similar apparatus. On account of the dependence of the blackness of the sky upon the transparency of the atmosphere, columns two and three might ordinarily be united. But the presence of fine dust in the atmosphere, while it increases the brightness of the sky to the eye, has little effect upon its transparency for the longer waves. Thus the conditions may frequently differ for spectroscopic work in the less refrangible region.

This grouping of familiar facts may be of service in emphasizing the diversity of conditions under which various classes of astronomical and astrophysical observations can be successfully made. It is evident that if the work of an observatory be chosen so as to harmonize with its environment, many results of great value may be obtained in localities which would generally be regarded as unfavorable. In the heart of a smoky city,

	Seeing	Transparency of atmosphere	Blackness of sky	Steadiness of instrument
STARS.				
Micrometric observations of double stars	A	B	B	A
Meridian observations:				
With meridian circle	A	C	C	A
With transit (time determinations)	B	C	C	B
Photography:				
With long focus telescope	A	B	B	A
With short focus telescope	B to C	A	A	B
Spectroscopy	A to B	B	B to C	B
Spectrography	B	B	B to C	B
Photometry:				
Absolute measures	B	A	A	B
Differential measures	B	B	B	B
NEBULÆ.				
Discovery	B	A	A	C
Micrometric measures	B	A	A	A to B
Photography:				
With long focus telescope	B	A	A	A
With short focus telescope	C	A	A	B
Spectroscopy and spectrography	C	B	B	B
Photometry:				
Absolute measures	B to C	A	A	B
Differential measures	B to C	B	B	B
MOON, BRIGHT PLANETS AND BRIGHT SATELLITES.				
Micrometric measures	A	C	C	A
Meridian observations	B	B	B	A
Photography	A	B	B	A to B
Spectroscopy and spectrography:				
Of general light	C	B to C	B to C	B
Of details	A to B	B to C	B to C	A to B
Photometry:				
Absolute measures	B	A	A	B
Differential measures	B	B	B	B
Observations of details	A	C	C	A to B
ASTEROIDS, FAINT PLANETS, AND FAINT SATELLITES.				
Discovery	A to B	A	A	A to B
Micrometric measures	A	B	B	A
Photography	A to B	A	A	A to B
Spectroscopy and spectrography	B	A	A to B	B
Photometry:				
Absolute measures	B	A	A	B
Differential measures	B	B	B	B
Observations of details	A	A to B	A to B	B
COMETS.				
Discovery	B to C	A	A	C
Micrometric measures	B	B	B	A to B
Photography	B to C	A	A	B
Spectroscopy and spectrography	C	B	B	B to C

	Seeing	Transparency of atmosphere	Blackness of sky	Steadiness of instrument
COMETS.				
Photometry:				
Absolute measures	C	A	A	B
Differential measures	C	B to C	B to C	B
SUN.				
Photosphere.				
Micrometric measures, visual and photographic observations of structure	A	C	C	A to B
Meridian observations	A	C	B	A
Photography, for measurement	A to B	B	B	A to B
Spectroscopy and spectrography:				
Of general light	C	C	C	B
Of details	A to B	C	C	A to B
Photometry of general light:				
Absolute measures	C	A	A	C
Differential measures	C	B to C	B to C	C
Heat radiation with thermopile, bolometer, or radio-micrometer:				
Absolute measures	C	A	A	CA
Differential measures	C	B to C	B to C	CA
Sun-Spots and Faculæ.				
Micrometric measures and visual observations of structure	A	C	C	A to B
Photography:				
Large scale, for details	A	C	C	B
Small scale, for positions	B	C	C	B to C
Of faculæ, with spectroheliograph	B	B	B	A to B
Spectroscopy and spectrography	B	B	B	B
Photometry:				
Absolute measures	B	A	A	B
Differential measures	B	B to C	B to C	B
Heat radiations, with thermopile, bolometer, or radio-micrometer:				
Absolute measures	B	A	A	BA
Differential measures	B	B	B	BA
Heat measures in spectrum	C	A to B	C	CA
Chromosphere and Prominences.				
Micrometric measures and observations of structure:				
Visual, with spectroscope	A	B	A	A to B
Photographic, with spectroheliograph	A to B	A	A	A to B
Spectroscopy and spectrography:				
Of prominences	B	A to B	A	B
Of chromosphere	A	A to B	A	A to B

illuminated by electric lights, where the sky is bright both day and night, delicate observations of chromospheric details, faint nebulæ and comets could not be advantageously made, nor could long exposure photographs of stars be taken. But even under such circumstances the staff of an observatory need not be idle. Observations of planets, satellites and double stars, spectroscopic studies of the stars, the solar photosphere, spots and faculæ, could be prosecuted, in most cases without serious hindrance from the surroundings. In fact, it would appear that certain observations could be made to the very best advantage under just such conditions, for the most successful existing records of the detailed structure of the solar photosphere and spots were obtained by Professor Langley at the Allegheny Observatory, in the midst of one of the smokiest districts of the United States. It is, indeed, a well-known fact that the presence in the atmosphere of a dense veil of smoke or haze is frequently accompanied by the most perfect seeing. It may be added that a very large proportion of Professor Burnham's double star discoveries and measures were made in Chicago, beginning with a six-inch telescope and concluding with the Dearborn refractor of 18½ inches aperture.

But while such considerations must affect existing institutions in their choice of work, the center of a city would certainly not be selected as the site of an observatory equipped for research in fields other than those just enumerated. Nor, in general, would a mountain peak. For notwithstanding a widespread impression to the contrary, the excellent atmospheric conditions enjoyed at the Lick Observatory do not seem to be common to all mountain summits.[1] So far as Professor Keeler and I could judge from observations made during our two weeks' stay on the summit of Pike's Peak (14,147 feet) in 1893, this would be an altogether unsuitable site for an observatory.[2] In 1894 I spent

[1] See Professor Holden's interesting memoir on "Mountain Observatories in America and Europe" (Smithsonian Miscellaneous Collections, No. 1035), which has come into my hands since this article was put in type.

[2] *A. and A.*, 13, 679, 1894.

a week with Professor Riccò at the Observatory on Mt. Etna (9800 feet). Here the atmospheric conditions are affected by the neighborhood of the great crater, when the wind blows the heated air and sulphurous fumes toward the east. But with the wind in other quarters the seeing at night is sometimes very fine. However, the air currents rising from the heated mountain slopes soon after sunrise spoil the seeing, so that solar observations must be made when the Sun is hardly out of the haze which enshrouds the Calabrian coasts.[1] Professor Swift considers the seeing by no means good at the Mt. Lowe Observatory in southern California. At the Pic du Midi Observatory (9590 feet) MM. Thollon and Trépied[2] found the seeing in 1883 to be good at night, excellent shortly after sunrise while the Sun was still low, and very bad during the rest of the day. At Mt. Hamilton the day seeing is ordinarily bad,[3] but at night the atmospheric conditions appear to be unsurpassed. In general it may be said that while mountain observatories frequently enjoy the advantage of a blue sky during the day, they ordinarily suffer the disadvantage of poor seeing after the early morning hours. In some cases, as at the Lick Observatory, the seeing by night is excellent. In other cases it is worse than that found at lower levels.

It would appear that the best seeing should be found on an extensive plateau. The conditions for solar work would probably be best if the plateau were covered with a dense forest, shielding the surface of the earth from the direct rays of the Sun, and greatly reducing the radiation of heat from the soil.

SELECTION OF THE SITE OF THE YERKES OBSERVATORY.

The principal investigations to be made at the Yerkes Observatory, as outlined in the plan of work drawn up by the writer in 1892,[4] are intended to include solar observations, compris-

[1] *Ibid.*, p. 685. [2] *C. R.*, **97**, 834, 1883.

[3] A recently published photograph of a Sun-spot made at the Lick Observatory seems to indicate that the day seeing is sometimes good. (*Pub. A. S. P.*, **9**, No. 54, 1897.)

[4] *A. and A.*, **11**, 791, 1892.

ing visual and photographic studies of the structure of the photosphere, spots and faculæ, photography of the faculæ, chromosphere and prominences with the spectroheliograph, spectroscopic observations, both visual and photographic, of all classes of solar phenomena, and bolometric and photometric investigations of various kinds; micrometric observations of double stars, nebulæ, planets, satellites, comets, etc.; photography of the Milky Way, stars, nebulæ, etc.; researches in stellar spectroscopy; meridian observations;[1] laboratory work of various kinds, principally with the spectroscope, bolometer and refractometer.[2] It is evident that in these various classes of work the greater part do not require very good seeing; but on account of the importance of the double star observations, and those of planets, satellites, the structure of the solar photosphere, etc., it was eminently desirable to choose a site at which the seeing would

[1] For the present to be confined mainly to time determinations.

[2] To form an idea of the minimum average conditions of seeing, transparency and blackness of the sky, and steadiness of the instruments permissible at a given observatory, the amount of time devoted to each class of work may be taken to indicate roughly the influence which the conditions required for these observations will have in deducing the average. It is practically impossible to determine the *value* of one class of work as compared with another, and a time basis, therefore, seems to be the only one that can be used. Times having been assigned in this way, as illustrated in the following example for the Yerkes Observatory, the averages may be taken at once. Such averages, while perhaps of no great value, at least indicate in a general way the nature of the conditions required. If, for example, the result B is obtained for the required average seeing, this of course does not mean that a site having an average seeing A would not offer greater advantages, but simply that with this minimum value the greater part of the observatory's work could be done without appreciable hindrance from atmospheric disturbance. It should be noted that, if few observations requiring seeing A are to be made, the difficulty of choosing a suitable site will be greatly decreased, for at most places good seeing is at least occasionally found.

Rough estimates of the relative amounts of time to be devoted each week at the Yerkes Observatory to the various classes of observations give: solar observations (three telescopes) 12; double stars (one telescope) 2; planets, satellites, comets, etc. (two telescopes) 5; stellar photography (portrait lens) 2; stellar spectrography (one telescope) 3; time service (transit) 1. Subdividing these classes of work still further, taking the corresponding data from the table, applying the proper times in place of weights and averaging, we have for the required minimum average conditions: Seeing, B. Transparency of atmosphere, B. Blackness of sky, B. Steadiness of instruments, A to B.

be the best attainable both by night and by day. Some of the other researches demand a dark sky and great transparency of the atmosphere, while for still others the principal requisite is complete protection of the instruments from vibrations of any kind. If there had been absolute freedom of choice, a site combining the excellent conditions for night work enjoyed at Mt. Hamilton with the good day seeing existing elsewhere would have been sought far and wide, without regard to geographical boundaries.

The practical choice of the site was materially influenced by the location of The University of Chicago. It was clearly understood by the members of The University Board of Trustees that if the Observatory were established upon The University campus there would be no possibility of entering successfully many of these important fields of investigation, and that a site must consequently be found outside the city of Chicago. At the same time the opinion was general that the Observatory could not be placed at a distance much greater than 100 miles from the city, without materially affecting its value as one of the departments of The University. There is no reason to suppose that the atmospheric conditions which prevail within a circle of this radius, with its center at Chicago, are surpassed by those existing at any point within a concentric circle having a radius of at least 500, perhaps even 1000 miles. Except in the case of the Lick Observatory,[1] which is about eighty miles by railway and carriage road from the University of California, all university observatories are located within a few miles of the other buildings of the institution. Harvard University has established a permanent observatory in Peru, but the principal observatory of the University is in Cambridge. If a university wishes to avail itself of the peculiar conditions existing in remote regions, it may do so by sending out expeditions or establishing branch observatories. It was believed that, in general, the principal observatory would be most advantageously situated if at no

[1] The site on Mt. Hamilton was selected before the Observatory entered into its present relationship with the University of California.

very great distance from the research laboratories of other departments.

As soon as it became generally known that the Yerkes Observatory was to be established outside the city of Chicago, numerous offers of land were made and other inducements were held out by individuals and by towns in various parts of the country. The offers included tracts of land in or near the towns of Morgan Park, Tracy, Highland Park, Downer's Grove, Hinsdale, Mt. Pleasant, Western Springs, La Grange, Glen Ellyn, Elmhurst, Elgin, Rockford, Peoria, Aurora, Waukegan, Belvidere, Sycamore, Marengo, Lena, Kankakee, Warren, Oregon, Princeton, Dixon, and Freeport in the state of Illinois; Lake Geneva in Wisconsin, and Pasadena in California. In company with a committee of the Board of Trustees the writer visited many of these places, and inspected the proffered sites. It soon became evident that the various tracts of land could be roughly classified as follows: (1) those in the suburbs of Chicago or other manufacturing cities; (2) those beyond the immediate suburbs, but situated at points where factories were likely to be established; (3) those situated where factories did not then exist, and were not likely to be established, near the shore of Lake Michigan; (4) those situated where factories did not then exist, and were not likely to be established, away from the vicinity of Lake Michigan. In order to assist in forming a correct estimate of the effect of smoke, electric lights, heated air, the jar produced by passing trains, and the neighborhood of a large body of water, upon the performance of the forty-inch telescope, I prepared a series of questions which were sent to Professors Barnard, Burnham, Hastings, Hough, Keeler, Langley, Newcomb, Pickering, and Young. The following abstracts of the replies received were embodied, with the conclusions which I have drawn from them, in a report presented to the Board of Trustees of The University of Chicago, on March 27, 1893. I may be permitted to express at this time the thanks of the Yerkes Observatory for these replies, as well as for the kindness of their authors in permitting them to be published.

QUESTION (1).

What do you consider the maximum distance at which a city like Chicago would appreciably affect observations with a forty-inch refractor?

ABSTRACTS OF REPLIES.[1]

I should regard a distance of ten miles as entirely outside the influence of the city dust and smoke.— *G. W. Hough.*

Evil effects of bodies of water, heated air and jar are entirely unnoticeable except in extreme cases. Smoke and electric lights more serious drawbacks, and city would produce injurious effect as far as these could be felt. — *Simon Newcomb.*

Depends in part on prevailing winds. Perhaps ten miles.— *S. P. Langley.*

Two miles if in direction of prevailing winds. Ten miles from borders of city if no prevailing wind. Should not be north of city.— *J. E. Keeler.*

Electric lights ten miles. Smoke perhaps five miles. Other causes one or two miles.—*E. C. Pickering.*

Twelve miles as good as sixty.— *S. W. Burnham.*

Uncertain. Perhaps ten miles, though electric lights might be felt further.— *C. A. Young.*

CONCLUSIONS.

A site not less than ten miles from the boundaries of the city should therefore be selected. Allowance must be also made for the future growth of the city.— *G. E. Hale.*

QUESTION (2).

What disadvantage arising from the proximity of Chicago would you consider most serious — smoke, electric lights, heated air, dust, jar or other?

ABSTRACTS OF REPLIES.

Smoke and electric lights.— *G. W. Hough.*

Smoke and electric lights decidedly. I do not suppose that heated air, dust or jar would produce any injurious effect. *Simon Newcomb.*

Smoke and dust with irregular hot air currents.— *S. P. Langley.*

Smoke.— *J. E. Keeler.*

Smoke and electric lights.— *S. W. Burnham.*

Smoke and electric lights.— *C. A. Young.*

[1] Professor Barnard's replies were not received in time to incorporate them into the report.

Depends on kind of work. For faint objects electric lights would be chief hindrance.— *E. C. Pickering.*

CONCLUSION.

Sites in the vicinity of factories or electric lights must be avoided.— *G. E. Hale.*

QUESTION (3).

Do you consider that the proximity of Lake Michigan would affect the seeing in any way?

ABSTRACTS OF REPLIES.

Cannot state definitely. I consider that the seeing at Evanston, on the shore of the lake, will compare favorably with that at any place in the eastern part of the United States.— *G. W. Hough.*

Do not know that any affect has ever been noticed.— *Simon Newcomb.*

Cannot say.— *S. P. Langley.*

Yes, probably.— *J. E. Keeler.*

Nothing is certainly known, but some bad effect would naturally be expected.— *E. C. Pickering.*

Would expect to have more nights with the best definition at points removed from the lake shore.— *S. W. Burnham.*

Presume it would, but would not venture to predict in what way. It might do as much good as harm taking the year through.— *C. A. Young.*

My experience goes to show the beneficial effect of a neighboring great body of water. Whether Lake Michigan could be considered of importance from this point of view I am unable to say.— *C. S. Hastings.*

QUESTION (4).

If so, would this effect differ in amount at points one hundred feet and twenty miles from the lake, respectively?

ABSTRACTS OF REPLIES.

Ten miles inland annual temperature curve is a number of degrees higher in summer and lower in winter than in immediate vicinity of lake shore. Atmospheric conditions hence somewhat different, but cannot say whether better or worse.— *G. W. Hough.*

Sufficiently answered under (3). *Simon Newcomb.*

If there is any disturbance I should think there would be a difference. *S. P. Langley.*

At a distance of twenty miles it seems probable that the influence of the lake would cease to be felt.—*J. E. Keeler.*

Probably there would be a decided difference in favor of the remote station.—*E. C. Pickering.*

One would expect that greatest disturbance due to intermingling of air over lake and land would occur near the line joining land and water.—*S. W. Burnham.*

I should think it would. So far as *general* meteorological influence is concerned there would be little difference; but any special local effect of moisture in the air would be much more powerful within a mile of the lake than at a greater distance.—*C. A. Young.*

CONCLUSIONS.

Reports obtained from Professor Mark W. Harrington, Chief of the Weather Bureau, show the average annual cloudiness at three lake ports to be:—Chicago, 51 per cent., Milwaukee, 54 per cent., Grand Haven, 58 per cent. At a point forty-seven miles from Lake Michigan the average annual cloudiness, as learned from the same source, is only 47 per cent. Therefore, on account of the increased cloudiness, and the possibility of injury to the seeing arising from proximity to so large a body of water, no site within twenty miles of Lake Michigan should be selected.—*G. E. Hale.*

QUESTION (5).

Do you consider that the certainty of having an absolutely unobstructed sky over an angle of 180° would compensate for any disadvantage which might result from the close proximity of the lake?

ABSTRACTS OF REPLIES.

The lake horizon is of minor importance, as no useful observations can be made below an altitude of about fifteen degrees.—*G. W. Hough.*

Under no circumstances can good observations be made with a large instrument near the horizon.—*Simon Newcomb.*

I cannot answer as to this.—*S. P. Langley.*

No, I see no particular advantage in having a clear horizon.—*J. E. Keeler.*

No, for observations near the horizon could seldom be required.—*E. C. Pickering.*

I do not consider a clear horizon all round to be a matter of much importance.—*S. W. Burnham.*

Certainly it would be a compensation to a certain extent. But if the proximity of the lake is seriously mischievous the extended view would not make up for it.— *C. A. Young.*

No.— *C. S. Hastings.*

CONCLUSIONS.

A site on the shore of the lake would have no advantage on account of the unobstructed easterly horizon. The certainty that no factories or buildings could ever be erected in the direction of the lake would be a distinct advantage, but not a sufficient one to compensate for the increased cloudiness as compared with an inland point.— *G. E. Hale.*

QUESTION (6).

At what maximum distance would an ordinary dwelling house interfere with observations with the forty-inch telescope?

ABSTRACTS OF REPLIES.

Single dwelling house at 200 feet distance would not sensibly affect the seeing, but it would not be admissable to surround the observatory with buildings at that minimum distance.— *G. W. Hough.*

Dwelling would not sensibly interfere at distance of 100 yards, unless telescope chanced to point directly over chimney.— *Simon Newcomb.*

An affair of prevailing winds. I should prefer to see none within one-half mile.— *S. P. Langley.*

At Mount Hamilton dwelling produces no injurious effect at distance of 100 yards.— *J. E. Keeler.*

One hundred yards.— *E. C. Pickering.*

An ordinary dwelling, or dwellings, as they would be placed with reference to this or any other observatory, would have no effect upon the atmospheric conditions.— *S. W. Burnham.*

Five hundred feet (?); am not sure.— *C. A. Young.*

CONCLUSIONS.

The observatory should stand in the center of a piece of land at least twenty acres in extent, from which all other buildings are excluded. To provide for future extensions it would be very desirable to devote not less than forty acres to the exclusive use of the observatory.— *G. E. Hale.*

QUESTION (7).

At what maximum distance would the jar of railroad trains interfere with observations with the forty-inch telescope?

ABSTRACTS OF REPLIES.

On sand or gravel a distance of 2000 feet from the railroad would be desirable. On clay or limestone jar may be sensible for a mile.—*G. W. Hough.*

Railway trains interfere with observations by reflection from mercury up to a distance of one and perhaps even one and one-half kilometers. Shaking of telescope would probably not be noticed at distance greater than 500 meters.—*Simon Newcomb.*

Depends on nature of underlying strata. With certain rock strata, at a very considerable distance, *e. g.*, several miles.—*S. P. Langley.*

It would be desirable to keep at least a quarter of a mile away from any railroad. Wind is much more serious.—*J. E. Keeler.*

Half a mile, but much depends upon the nature of the ground.—*E. C. Pickering.*

The passing by of railroad trains would be no objection to the use of this or any other telescope. A small puff of wind would produce more vibration than any number of railroads.—*S. W. Burnham.*

Quarter to half a mile, unless on a rocky ledge.—*C. A. Young.*

CONCLUSIONS.

The observatory should be situated at least half a mile from any railroad. Underlying strata of sand or gravel are most suitable. Rock should be avoided.—*G. E. Hale.*

ADDITIONAL REMARKS AND SUGGESTIONS.

To be of the greatest benefit to science the telescope should be mounted at some such point as Mt. Hamilton, California; Arequipa, Peru; or the Peak of Teneriffe.—*Simon Newcomb.*

In the absence of local knowledge the opinions I have expressed cannot be regarded as having great weight. They might be seriously modified by an examination of the peculiarities of the place.—*E. C. Pickering.*

I should select a point in a westerly direction from the city, and not more than twenty miles distant. Such a place can easily be found near some one of the numerous railroads, and be conveniently accessible at all times of day and night. This is a matter of much importance in the practical working of the observatory, and should not be overlooked.—*S. W. Burnham.*

The adoption of the conclusions arrived at by the writer after careful consideration of these replies led to the imme-

diate rejection of most of the places named. Further study finally resulted in the selection by the Board of Trustees of a tract of land on the shore of Lake Geneva, Wisconsin, which had been offered to The University by Mr. John Johnston, as the site of the future Observatory. Lake Geneva is a beautiful body of water, about eight miles long and one mile wide, situated in southern Wisconsin seventy-five miles by rail from Chicago.

The region is one where the mean annual cloudiness is low for this part of the United States, there is but little dust, and the nights of the best observing months are usually calm. The land presented to The University is a tract fifty-three acres in extent on the north shore of the lake, near its western end, and about one mile distant from the small town of Williams Bay, where a branch line of the Chicago and Northwestern Railroad terminates. The center of motion of the forty-inch telescope is about 240 feet above the level and 1800 feet from the shore of Lake Geneva,[1] and thirty-eight miles from the shore of Lake Michigan. The building is so situated in the midst of the grounds that it seems to be secure from any possible disturbance from without. Unlike most places in the vicinity of Chicago, the region about Lake Geneva offers no advantages to the manufacturer, and it is very improbable that the Observatory will ever be disturbed by factories in its vicinity. The lake is a favorite summer resort, and many Chicago people have country houses upon its shores. But these are for the most part well removed from each other and from the Observatory, and even if the present number were doubled or trebled the atmospheric conditions would not be appreciably affected. There are no electric lights nearer than Lake Geneva, a town of some 3000 inhabitants, about seven miles from the Observatory, at the eastern extremity of the lake. The surrounding country is a succession of woodland and cultivated fields, with the trees predominating in the near neighborhood of the Observatory. In general the site resembles that of the Astrophysical Observatory at Potsdam. The grounds of

[1] According to rather uncertain data the center of motion of the telescope is about 1200 feet above sea level.

the Observatory provide ample space for the erection of instruments in the open air. The soil is largely gravel, and as the nearest railroad is fully a mile and a half away there seems to be nothing to fear from vibrations of any kind.

Seemingly the only question which might arise regarding the suitability of this site for the purposes of the Yerkes Observatory depends upon its proximity to a small body of water. This question suggested itself to me the first time I visited the lake, and it was subsequently given very careful consideration. The opinions expressed by the various astronomers regarding the probable effect upon the seeing of so large a body of water as Lake Michigan showed that little or nothing was actually known from experience, although a very large number of observatories in all parts of the world are situated near oceans, lakes, and rivers. Such testimony made it seem extremely improbable that Lake Geneva, the area of which is about $\frac{1}{20000}$ that of Lake Michigan, could appreciably affect the seeing. Two possible ways of determining the matter suggested themselves: (1) by means of a long series of observations extending through different seasons, to be made with a small telescope on the proposed site of the Observatory; (2) through an examination of observations made elsewhere with large instruments under as nearly as possible identical conditions. The first method was evidently one in which no great reliance could be placed, for when the seeing is good with a small telescope it by no means follows that it is good with a large one.[1] The second method seemed

[1] Observations were subsequently made in the summer months on the observatory site with a four-inch Clark refractor, and so far as could be judged with an instrument of this size, the seeing was very good on these occasions. In the few observations which it has been possible to make during the present winter, the neighborhood of the lake seems to have had no effect upon the seeing. Since its surface has been covered with a layer of ice nearly a foot thick, rendering it similar to the snow-covered fields in the vicinity, any possible effect due to a body of water differing in temperature from the air has been eliminated. Speaking generally, the seeing was perhaps rather better before the ice appeared, but the observations have necessarily been so few that no conclusions can be drawn. On many occasions the atmosphere has been exceedingly transparent, and I have several times observed the sky near the Sun to be as blue as it ever appeared during my visit to Mt. Etna.

much more likely to give reliable results, particularly on account of Professor Burnham's experience in observing double stars with the sixteen-inch telescope of the Washburn Observatory at Madison, Wis. The center of motion of this instrument is about 120 feet above the level of Lake Mendota, which is only about 650 feet away. In the immediate vicinity there are other small lakes, so that the Observatory is almost completely surrounded by water. Nevertheless Professor Burnham was never able to detect any inferiority of the seeing which could be attributed to the neighborhood of the lakes. He was strongly of the opinion that the site at Lake Geneva was quite as good as any to be found within one hundred miles of Chicago. On account of Professor Burnham's long experience as an observer and his previous study of the matter in connection with his selection of the site of the Lick Observatory, his opinion that the Yerkes Observatory might be established at Lake Geneva without fear of local atmospheric disturbance was accepted as final. The work of designing the buildings of the future Observatory was then undertaken.

YERKES OBSERVATORY,
February 1897.

(*To be continued.*)

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XVIII.

By Henry A. Rowland.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3562.549		0000	3567.517	Fe	1
3562.689		0000	3567.594		0000
3562.746		0000	3567.711		0000
3562.848		0000	3567.835		4
3563.065	Co	0 N	3567.881		2
3563.152		000	3568.083		00
3563.298		000 N	3568.147		0000
3563.542		000 N	3568.281		0000
3563.750		00	3568.387		00
3563.855		0000	3568.451		0000
3563.928		000 N	3568.587	Fe	3
3564.065		0000 N	3568.767		00
3564.264	Fe-Co	4	3568.968	Fe	3
3564.418		0000	3569.122	Fe	4
3564.537		0000	3569.281		0000
3564.664 } S	Ti	3	3569.371		0000
3564.705 }	Fe	2	3569.523	Co	5
3564.822		000	3569.649	Mn	4
3564.935		00	3569.761		0000
3565.075	Co	4	3569.873		0
3565.128		3	3569.958	Mn	2
3565.268		1 N	3570.060		000
3565.445		3 N	3570.183 } S	Mn	4
3565.535 S	Fe	20	3570.273 }	Fe	20
3565.735		4	3570.415 S		4
3565.855		000 N	3570.566		0000
3565.977		0	3570.660		0
3566.111	Ti	1	3570.736		0000
3566.227		000	3570.826		0000
3566.314		2 N	3571.000		0000
3566.454	Cr	0 N	3571.126		0
3566.522	Ni	10	3571.250	Pd	0000
3566.624		0	3571.374	Fe	3
3566.728		1	3571.546		00
3566.807		0000	3571.690		0000
3566.897		0000	3571.828		2
3566.984		0000	3571.913		000
3567.061		1	3572.014	Ni	6
3567.181	Fe	2	3572.155	Fe	5
3567.334		0000 N	3572.280		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3572.460		0000	3578.530	Fe	4
3572.617		4	3578.702		0
3572.712	-,Sc	6	3578.832	Cr	10
3572.890	Cr?	00	3578.978		000
3573.017		0000 N	3579.047	Co	0
3573.087		0000 N	3579.122		00
3573.207	Fe	1 N	3579.185		00
3573.320		0000	3579.268		0000 N
3573.417		0000	3579.508		000 N
3573.540	Fe	2	3579.648		0000
3573.650		0000	3579.702		1
3573.792	Ti	2	3579.812		0000
3573.874	Fe	3	3579.974		2
3573.975	Fe	3	3580.098		000 N
3574.050		2	3580.227		00
3574.135		0	3580.356		1 N
3574.174		0	3580.552		1
3574.297		0000	3580.682		1 N
3574.394	Ti	0	3580.898		0 N
3574.499		000	3581.067		5
3574.559	La	1	3581.184		1
3574.723		0000 N	3581.349 s	Fe	30
3574.944	Cr	0	3581.531		1
3575.106	Cr-Co	5	3581.617		0
3575.260	Fe	3	3581.805	Fe	2
3575.391	Fe	3	3581.957	Fe	2
3575.494	Fe	2	3582.081		1
3575.533	Co	2	3582.231		00
3575.699		000	3582.345	Fe	5
3575.904	Zr	00	3582.471		2
3576.118	Fe	4	3582.577		000
3576.296		0000	3582.711	Fe	2
3576.393		0000	3582.838	Fe	3
3576.469		4	3582.884		00
3576.527	-,Sc?	3	3583.017		0000
3576.739		0000	3583.104		000
3576.906	Fe	2	3583.244		0000
3577.003	Zr	1	3583.357		000
3577.099		0000	3583.481 s	Fe	5
3577.203		000	3583.581		0000
3577.299		000	3583.637		0000
3577.384	Co	1	3583.737		0000
3577.532		000	3583.837	-,C	3
3577.605		1	3584.051	-,C	3
3577.705		0000	3584.147		0000
3577.885		0000	3584.237		0000
3578.014	Mn	5	3584.397		0000
3578.138		0000	3584.457		000
3578.240	Co	1	3584.523		0000
3578.358	Ti	00	3584.616		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3584.660 s	Y	2	3590.803	Fe	00
3584.800	Fe	6	3590.976		0000 N
3584.940	Co	5	3591.149	Fe	1
3585.105	Fe	6	3591.283		0000
3585.214		000	3591.366		0000
3585.310	Co	5	3591.496	Fe	2
3585.479	Fe	7	3591.629	Fe	2
3585.658		2	3591.732		0000
3585.777		000 N	3591.885		0000 N
3585.859	Fe	6	3592.045		0000 N
3585.984 s [1]	C	0	3592.169	V?	2
3586.047 s	C	00	3592.348		0000
3586.157	Co	1	3592.412		000
3586.268	Fe	4	3592.508		0000
3586.390		000	3592.619	Fe	1
3586.494		00	3592.745		000
3586.624		0000	3592.819	Fe	3
3586.684	Mn	4	3592.935		0000
3586.890		3	3593.040	Y	0
3587.024		0	3593.158		0000
3587.130	Fe	8	3593.223		0
3587.286	Ti	2	3593.402		000
3587.370	Co	7	3593.481	Fe	3
3587.497		000	3593.636	Cr	9
3587.574	Fe	3	3593.835		000
3587.757	C	0000 N	3593.935		000
3587.899	Fe	5	3594.138		000 N
3588.084	Ni	6	3594.245		000
3588.263	C	000	3594.458		0000
3588.387		0	3594.528		0000
3588.466	C	00	3594.784	Fe	6
3588.563		0000	3595.017	Co	3
3588.675		3	3595.161		0000
3588.763	Fe	4	3595.256	Mn	1
3588.916	C	0000	3595.449	Fe, Ti	2
3589.065	Fe, C	2	3595.554		0000
3589.253	Fe	4	3595.681		0000 N
3589.363	C	0000	3595.824		000
3589.446	C	000	3596.012	Fe	1
3589.601	Fe	2	3596.195	Ti	4
3589.773		5	3596.346	Fe	1
3589.908		5 d?	3596.454		0000
3590.023	C	0000	3596.534		0000
3590.109	Mn, C	00	3596.651	Co	0
3590.235	Fe, C	1	3596.787		0000
3590.383		0000	3596.894		0000
3590.443		0000	3597.001		0000
3590.509 [2]	C	2 N	3597.189 s	Fe	5 d?
3590.609		2	3597.294		0000
3590.651		2	3597.394		0000Nd?

[1] Beginning of second head of carbon band.

[2] Beginning of first head of carbon band.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3597.541		0000	3603.719		2
3597.654		0000	3603.762		2
3597.854	Ni	8	3603.832		2
3597.994	Fe	00	3603.922	Ti	3
3598.121		0000	3603.972	Fe	4
3598.167		0000	3604.091		1
3598.324		0000 N	3604.259		0000 N
3598.414		1	3604.419	Ti	1
3598.611		0000 N	3604.519	Fe	2
3598.754		0000	3604.605		0000
3598.862	Ti, Fe	1	3604.699		0000
3598.953		0000	3604.843		1
3599.081	Fe?	2	3604.945		0000
3599.128	Fe?	2	3605.073		000
3599.287	Fe	2	3605.159		000
3599.523		000 N	3605.222		00
3599.686		0000	3605.341	Fe?	5
3599.774	Fe	3	3605.479 s	Cr	7
3599.906		0000	3605.615 } s	Fe	4
3599.973		0000	3605.669 }	Fe	4
3600.112		1	3605.832		0000 N
3600.313		0000 N	3606.059	Fe	1
3600.513		0000	3606.179		000
3600.596		0000 N	3606.272		0000
3600.733		0000	3606.391		0000
3600.880 s	Y	3	3606.518		0
3600.966		0000	3606.678	Fe	2
3601.060		0000	3606.751		1
3601.220		0000 N	3606.838 s	Fe	6
3601.340		000	3606.994	Ni	1
3601.426		0000	3607.144		0000
3601.500		0000 N	3607.264		0000
3601.570		000	3607.391	Zr	0000
3601.686		0000	3607.518		000
3601.806	Cr	0	3607.672	Mn	3
3601.930		0000	3607.764		0000
3602.060 s	Y	1	3607.911		0000 N
3602.210	Co	3	3608.004		000 N
3602.253	Fe	2	3608.111		0000
3602.559	Ni	4	3608.149		2
3602.611	Fe	3	3608.201	-,Fe	4 d?
3602.686	Fe	4	3608.458		000 N
3602.739		0000	3608.551		000
3602.849		000	3608.630	Mn	3
3602.912		0	3608.728		00 N
3603.019		0000	3608.778		000 N
3603.112		0000	3608.871		1 N
3603.238		1	3609.008 s	Fe	20
3603.354	Fe	5	3609.134		0 N
3603.579		0000	3609.244		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3609.467	Ni	5d?	3615.462		0000
3609.611		2	3615.531	Co, Mn	00
3609.697	Pd	00	3615.669		0000 N
3609.853		0000 N	3615.802	Fe	3
3609.907		000 N	3615.949		0000
3610.017		0000 N	3616.100	Fe	0
3610.195		0 N	3616.294		2
3610.305	Fe, Ti	5	3616.357		1
3610.435	Mn	2	3616.465	Fe	1
3610.599	Cd?	4	3616.569		0000
3610.647	Ni	5	3616.710	Fe	4
3610.841	Fe	3	3616.866		0000 N
3610.970		0000	3617.016		0000 N
3611.083		0000 N	3617.149		0
3611.189 s	Y, Mg?	2	3617.243	Fe	1
3611.323		1	3617.315		0000
3611.443		000	3617.457	Fe	3
3611.598	Ni	0	3617.575	Mn	2
3611.697		00	3617.677		000
3611.862	Co,-	2	3617.855 } s	Ca?	1
3612.037	Zr	00	3617.934 }	Fe	6
3612.213 s	Fe	4	3618.098		2 N
3612.383		0000 N	3618.228		0000
3612.520		0000 N	3618.325		000
3612.657		000	3618.441	Ca?	3
3612.743		000	3618.532	Fe	3
3612.882	Ni	6d?	3618.661		00
3613.079	Fe, Cd	3	3618.753		1 N
3613.247		2	3618.919 s	Fe	20
3613.314	Fe	1 N	3619.061		0
3613.470		0000	3619.138		00 N
3613.587	Ti	2	3619.253		0
3613.739	Ti	2	3619.412	Mn	1
3613.857		0	3619.539	Ni	8
3613.947	-,Sc	4	3619.675		0 N
3614.019		3	3619.809		00
3614.090		0000	3619.915	Fe	2
3614.159		0000	3620.076		1
3614.257	Fe	2	3620.171		0
3614.446		0000 N	3620.295		0000
3614.549		0000	3620.387	Fe	2
3614.697	Fe	2	3620.578		0000
3614.789	Zr	0000	3620.609	Fe	3
3614.856	Fe	2	3620.758		0000 N
3614.922		2	3620.911		0000 N
3615.029		00	3621.018	Fe	1
3615.142		0000	3621.110	Y?	00
3615.222		0000	3621.244		3
3615.336	Fe	1	3621.340		2
			3621.400		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3621.520		0000 N	3627.763		000
3621.612 s	Fe	6	3627.855		00
3621.740		0000	3627.953	Co	4
3621.864	Fe	2	3628.099		0000 N
3622.007		0000 N	3628.238	Fe	2
3622.147 s	Fe	6	3628.419		000 N
3622.297		0	3628.579		0000 N
3622.407		0000	3628.739		00
3622.577		0000 N	3628.847 s	Y, Mg?	2
3622.694		0000 N	3628.967	La	2
3622.794		000	3629.019		0000
3622.934		0000	3629.146		0000
3623.040		0000	3629.286		0000Nd?
3623.180		0000	3629.492		000 N
3623.234		0000	3629.652		0000 N
3623.362 s	Fe	5	3629.877	Mn	1
3623.460		0000	3630.045	Ni	1
3623.588 s	Fe	2	3630.164		1
3623.650		00	3630.252		0000
3623.750		0000	3630.374		0
3623.925	Mn, Fe	4	3630.492	Fe	4
3624.057		1	3630.618		0000
3624.204		2	3630.718		0000
3624.258	Ca	3	3630.798		0000
3624.447	Fe Co	3	3630.876		4
3624.600		0000 N	3630.918		3
3624.707		0000	3631.124	Ca	2
3624.873	Ni	4	3631.244	Fe	3
3624.979	Ti, Fe	5	3631.404	Co	1
3625.103	Co	1	3631.495	Ti?	0
3625.287	Fe	5	3631.605 s	Fe	15
3625.389		0000	3631.725		0
3625.506		0000 N	3631.850	Co	1
3625.641		1	3631.928		000 N
3625.766		0000 N	3632.098		2
3625.893		000	3632.193	Fe	3
3625.993		0000	3632.312		0
3626.073		0000	3632.438		00
3626.156		0000	3632.585		0000
3626.249	Ti	0	3632.700	Fe	3
3626.327	Fe	1	3632.832		0000
3626.526		0000 N	3632.979	Co, Cr, Zr	1
3626.633		0000 N	3633.123	Fe	4
3626.746		0000	3633.215		2
3626.877		2	3633.277	Y	2
3627.046		0000 N	3633.447		0000 N
3627.201	Fe	2	3633.651	Ti	00 Nd?
3627.309		000	3633.791		000
3627.499		000 N	3633.974	Fe	4
3627.596		000 N	3634.031		1

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3634.144		0000 N	3639.588	Co	2
3634.337		3	3639.663	Pb	1
3634.417		000	3639.833		0000
3634.471	Fe	3	3639.943	Cr	2
3634.551		1	3640.123		0000
3634.611		00	3640.256		0000 N
3634.674		000	3640.403		0000
3634.757	Pd	0000	3640.535 s	Cr-Fe	6
3634.849	Fe-Co	4	3640.783		000
3635.004		0000	3640.903		0000
3635.091	Ni	3	3641.043		0000
3635.164		1	3641.170		1
3635.224		0000	3641.366		0000 N
3635.336	Ti, Fe	2	3641.473	Ti	4
3635.419		000	3641.597	Mn, Cr	1
3635.491		00	3641.784	Ni	1
3635.608 s	Ti, Fe	4	3641.930	Co	0
3635.791		000 N	3641.970	Cr	1
3635.967		00	3642.102	Fe	00
3636.034		0000	3642.285		0000 N
3636.184		0000	3642.419		000 N
3636.305	Fe	3	3642.536		000
3636.377	Fe	2	3642.675		0000
3636.624		1	3642.820	Ti	7
3636.728	Cr	2	3642.912	Sc	2
3636.802	Fe	2	3642.965		3
3636.890	Co	2	3643.109		0000
3637.004		0000	3643.262	Fe	2
3637.139		2	3643.342	Co	1
3637.197	Fe	1	3643.492		0000
3637.397	Fe	1	3643.615		0000
3637.456		0000	3643.764	Fe	4
3637.583		0000	3643.867	Fe?	2
3637.693		00	3643.949		3
3637.876	Fe	0	3644.089		000
3638.011	Fe	4	3644.212		0000 N
3638.113		000	3644.289		0000 N
3638.196		0000	3644.455		0000 N
3638.242		1	3644.555	Ti, Ca	5
3638.306		1	3644.729		0
3638.383		1	3644.833	Ti, Fe	1
3638.442 s	Fe	3	3644.932	Fe	3
3638.610		0000	3645.117		0
3638 743		0000	3645.221	Fe	2
3638.910		0000	3645.325		0000
3639.043		000	3645.429		3
3639.168	V	0	3645.475	Sc?,-	3
3639.270		0000	3645.552	La	00
3639.423		1	3645.636	Fe	3
3639.470		0000	3645.765		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3645.967	Fe	4	3652.691 s	Co	3
3646.074		0000	3652.820		0000Nd?
3646.128		0000	3653.023		0000
3646.236		00	3653.160		0000
3646.335	Ti	1	3653.260		0000
3646.491		0000 Nd?	3653.340		0000
3646.643		000	3653.492		1
3646.757		2	3653.637 s	Ti	5
3646.948		000 N	3653.799		0000
3646.976		00 N	3653.900	Fe	2
3647.128		2	3654.052	Cr	2
3647.234	Co	0	3654.119	Fe	2
3647.394		0000 Nd?	3654.266		0000 N
3647.561	Fe	4	3654.392		0000 N
3647.701		0	3654.526		0000
3647.808		0	3654.586	Co	00
3647.988 s	Fe	12	3654.738	Ti	2
3648.221	Co	0 N	3654.813	Fe	1
3648.367		0	3654.999	Hg?	0000
3648.461		00 N	3655.143	Fe	2
3648.669	Cr	0	3655.199		0000
3648.778		0000	3655.359		00
3648.898		0000	3655.495		1
3648.954		000	3655.609	Fe	3
3649.137	Cr	1	3655.719		0000
3649.234		0000	3655.801		3
3649.324		0000	3655.990		0000
3649.438	Fe	4	3656.080		0000 N
3649.476	Co	3	3656.217		0000
3649.654	Fe, La	5	3656.358	Fe	3
3649.838		00	3656.404	Cr	2
3649.977	Co	1	3656.496		1
3650.178	Fe	4	3656.687		000
3650.423	Fe	5	3656.844		0000Nd?
3650.507		0000	3656.997		0000 N
3650.681		2	3657.104	Co	0
3650.860		0000 N	3657.275	Fe	2
3651.027		0000 N	3657.437		0000 N
3651.179		00	3657.562	Fe	1
3651.247	Fe,-	6	3657.710		0000 N
3651.337		00	3657.850	Fe	1 N
3651.400		0000	3657.957		0000
3651.493		0000 N	3658.044	Co, Fe, Mn	3
3651.614	Fe	7	3658.163		1
3651.704		1	3658.238	Ti	1
3651.940	Sc	4	3658.306		0000
3652.061		1	3658.413		0000 N
3652.247		0000	3658.529		000 N
3652.400		00	3658.689 s	Mn Fe	1
3652.537		0000	3658.783		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
[illegible]		0000 N	[illegible]	[illegible]	[illegible]
[illegible]		0000 N	[illegible]	Fe	[illegible]
[illegible]		0000 N	[illegible]		[illegible]
[illegible]		0000 N	[illegible]		[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]	Fe, [illegible]	[illegible]	[illegible]		[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]		0000 N	[illegible]		[illegible]
[illegible]		00	[illegible]		[illegible]
[illegible]	Fe	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Mn	1	[illegible]	Fe	[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	Fe	[illegible]
[illegible]		[illegible]	[illegible]		[illegible]
[illegible]		0000 N	[illegible]		[illegible]
[illegible]		000 N	[illegible]		[illegible]
[illegible]		0000	[illegible]	[illegible]	[illegible]
[illegible]		0000	[illegible]	Fe	[illegible]
[illegible]	Fe	3	[illegible]		[illegible]
[illegible]		0000	[illegible]	Fe	[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]		0000	[illegible]	[illegible]	[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]	[illegible]	1	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		0000	[illegible]	[illegible]	[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]		0000 N	[illegible]	[illegible]	[illegible]
[illegible]		000	[illegible]		[illegible]
[illegible]	Fe, Cr	[illegible]	[illegible]		[illegible]
[illegible]		0000	[illegible]		[illegible]
[illegible]		0000 N	[illegible]	Fe	[illegible]
[illegible]		0000 N	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	Fe	[illegible]
[illegible]	Fe	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]		[illegible]
[illegible]	Fe	[illegible]	[illegible]	Fe	[illegible]
[illegible]		0000 N	[illegible]		[illegible]
[illegible]		0000 N	[illegible]	[illegible]	[illegible]
[illegible]		0000 N	[illegible]	[illegible]	[illegible]
[illegible]	Fe	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]		000	[illegible]		[illegible]
[illegible]		0000	[illegible]	[illegible]	[illegible]
[illegible]		0000 N	[illegible]	[illegible]	[illegible]
[illegible]	Fe	[illegible]	[illegible]		[illegible]

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3670.860		00 N	3677.231		0000
3670.953	Fe	4	3677.308		0000
3671.046		0000 N	3677.457	Fe	4
3671.226		0000 N	3677.598	Fe	3
3671.358		000	3677.650		3
3671.412	Zr	0	3677.764	Fe	5
3671.506		0000	3677.831		3
3671.660	Fe, Pb	0	3677.991		3
3671.819	Ti	3	3678.045		2
3671.993		0000	3678.236		000 N
3672.083		0000	3678.370		1 Nd?
3672.260		000	3678.491		0000
3672.452		0000	3678.591		0000
3672.601		000	3678.718		0000
3672.742		0000	3678.864		0000
3672.851	Fe	3	3679.002	Fe	4
3672.939		0000	3679.139	Fe	2
3673.049		0000	3679.248		000 N
3673.182		0000	3679.488	Fe	1
3673.226	Fe	3	3679.575		0000
3673.362		0 N	3679.675	Fe	1
3673.562		000	3679.821		2
3673.679		0000	3679.947		0 N
3673.819		00	3680.069 s	Fe	9
3673.909		0000	3680.137		0 N
3674.025	Fe	2	3680.261		0 N
3674.108	Fe	4	3680.347		0000 N
3674.287	Ni	4	3680.525		2
3674.452		0000	3680.641		0000
3674.550	Fe	2	3680.801		3
3674.699		0000	3680.937	Fe	4
3674.865	Zr	1	3681.081		3
3674.909	Fe	2	3681.254		0000
3675.059		0000	3681.368	Fe	2
3675.135		0000	3681.501		0000
3675.255		0000 N	3681.604		0000
3675.430		1	3681.787	Fe	3
3675.585		00	3682.021	Fe	0
3675.692		0000	3682.161	Mn	000
3675.825	V	1	3682.310		2
3675.902		0	3682.382	Fe	5
3676.018		0000	3682.661		00 N
3676.112		000	3682.807		0 N
3676.291		0000	3683.021		000 N
3676.457	Fe, Cr	6	3683.182	Co	3
3676.698	Co	2	3683.229	Fe-V	4
3676.836		0000	3683.514		0000
3676.950		0000	3683.617	Pb?	0000
3677.016	Fe	3	3683.761		2
3677.098		0000	3683.893		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3684.020		0000	3690.019	Fe	1
3684.106		0000	3690.053	Ti	2
3684.258 s	Fe	7 d?	3690.205		0000
3684.360		0000	3690.420	V-Pd	1
3684.460		0000 N	3690.599	Fe	2
3684.600	Co-	000 N	3690.732		0000
3684.680	Mn	000 N	3690.870	Co-Fe	4
3684.858		0000 N	3690.999		0000
3685.000		0000 N	3691.112		0000 N
3685.140		000 N	3691.315		000 N
3685.339	Ti	10 d?	3691.452	Fe, Mn	2
3685.665	Mn, Cr	1	3691.534		0000
3685.810		0000	3691.674		0000
3685.913		0000	3691.824		0000
3686.020		0000	3691.954		0000
3686.141	Ti-Fe	6	3692.101		0000
3686.246		0000	3692.251		0000
3686.326		0000	3692.364	V	1
3686.399	Fe, V	3	3692.498		0000
3686.520		0000	3692.578		0000
3686.611		0000	3692.708		0000
3686.813		000	3692.790	Fe	2
3686.926	Cr	1	3692.954	Mn	000 N
3687.010		000	3693.024		0000
3687.083		0000	3693.170	Fe	3
3687.234	Fe	3	3693.258	Co	1
3687.380	Cr	1	3693.384		0000
3687.473		1	3693.504		000
3687.610 s	Fe	6	3693.616	Co	1
3687.690	Cr?	000	3693.804	Mn	0
3687.800	Fe	4	3693.921		0
3687.899		0000	3694.077	Ni	2
3688.005		0000	3694.164	Fe	4
3688.125		0000	3694.344		3
3688.210	V	1	3694.576	La	1
3688.312		2	3694.791		0000
3688.425		0000	3694.954		000
3688.558	Ni	4	3695.041		0000
3688.617	Fe	3	3695.194 s	Fe	5
3688.810		0000	3695.344		0000 N
3688.943		2	3695.479	V	0
3689.013	Fe	1	3695.658	Fe, Mn	1
3689.141		1	3695.789		2
3689.219	Fe	1	3696.006	Fe, V	1
3689.345		0000 N	3696.175	Fe	0
3689.459		000	3696.290		0000 N
3689.513		3	3696.433		0
3689.614	Fe	6	3696.520		0
3689.769		0000	3696.660		000
3689.839		0000	3696.707	Mn	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3696.800	Mn	0	3703.242		000
3696.890		000	3703.309		000 N
3696.949	Ti	00	3703.586		000
3697.047	Fe, Ni	1	3703.683	Fe-V	{ 4
3697.243		000 N	3703.729		{ 3
3697.397		000 N	3703.834	Fe	3
3697.567	Fe	5	3703.962	Fe	2
3697.677		3	3704.176		{ 2
3697.883		000	3704.221	Co	{ 3
3698.007		000	3704.341		000
3698.153		1 N	3704.435		00
3698.303	Ti, Zr	2	3704.485	Ti	0
3698.463		000 N	3704.603	Fe	4
3698.613		00 N	3704.842	V	1
3698.744	Fe	4	3704.935		000
3698.830		00	3705.051		000
3698.940		000	3705.171	V	0
3699.023		000	3705.251		000
3699.153	Co	00	3705.401		00 N
3699.283	Fe	3	3705.561		00 N
3699.413		000 N	3705.708 s	Fe	9
3699.533		000	3705.849		2
3699.710		000	3705.968		000 N
3699.877		000	3706.075		00
3699.962		1	3706.175	Mn-	6 d?
3700.062		000	3706.363	Ti	3
3700.182	Ti	00	3706.475		000
3700.269		00	3706.621		000
3700.406		000	3706.701		000 N
3700.479		1	3706.835		000 N
3700.596		000	3707.021		000
3700.737		1	3707.186 s	Fe	5
3700.876		000	3707.315		000
3700.942		000	3707.468		2 N
3701.052		000	3707.600	Co	2
3701.132		000	3707.702	Ti	2
3701.234	Fe	8	3707.815		000
3701.409		000	3707.959	Fe?	5 d?
3701.512		000	3708.068	Fe	5
3701.672		000	3708.224		00
3701.749		000	3708.327		000
3701.866	Mn	0	3708.454		000 N
3702.006		000 Nd?	3708.574		000 N
3702.170	Fe	4	3708.741		1
3702.382	Co	2	3708.834	Ti, V	000
3702.409	Ti	2	3708.964	Co	1
3702.629	Fe	4	3709.170		1
3702.782		000 Nd?	3709.290		00 N
3702.962		000 Nd?	3709.389 s	Fe	8
3703.099		000 N	3709.540		0 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3709.675	Fe	1	3716.293		0000 N
3709.808	Fe	1	3716.517		00
3709.967		000	3716.591 s	Fe	7
3710.094	Ti	0	3716.677		00
3710.214		00	3716.838		0000
3710.304		000	3716.905		0000
3710.431 s	Y	3	3717.084		000 N
3710.587		00 N	3717.211		000
3710.777		00 N	3717.326		00
3710.880		000	3717.410		0000
3711.020		000 N	3717.539	Ti	2
3711.254		000	3717.695		0000 N
3711.364	Fe	4	3717.812		0000
3711.440		000	3717.872		0000
3711.552	Fe	3	3717.975		0
3711.674		000	3718.093		000 N
3711.804		000 N	3718.291		0 N
3711.923		000 N	3718.367		000
3712.079		0	3718.460		000
3712.229		00	3718.554	Fe	4
3712.319	Co	00	3718.665		0000
3712.443		000	3718.754		000 N
3712.539		000	3718.845		0000
3712.666		000	3718.978		0000
3712.856		000	3719.070	Mn, Pd	1
3712.906		000	3719.168		0000
3713.037		2	3719.332		0000 N
3713.087	Cr	3	3719.405		0000
3713.239		000	3719.545		0000 N
3713.346		000	3719.598		000 N
3713.479	Ni	00	3719.683		000 N
3713.693		000 N	3719.796 [1]		0 N
3713.853	Ti	0	3719.905		0000 N
3713.973		000	3720.084 s	Fe	40
3714.109		000 N	3720.184		0000
3714.296		000 N	3720.305		0 N
3714.359		000 N	3720.400		000 N
3714.546		000	3720.544		00 Nd?
3714.706		000	3720.704		0000Nd?
3714.813		000	3720.832		0000 N
3714.926	Zr	0	3720.930		0000
3715.069		000	3721.048		0000
3715.179		000	3721.171		0000
3715.319		2	3721.212		0000
3715.536		0000	3721.326		2
3715.615	Mn?	4	3721.418	Fe	3
3715.853		0000 N	3721.540	Fe	2
3715.938		0000	3721.647	Fe	2
3716.054	Fe	3	3721.779	Ti	4 d?
3716.172		0000			

[1] This line is variable, though not an atmospheric line.

ON THE OCCURRENCE OF VANADIUM IN SCANDINAVIAN RUTILE.[1]

By B. Hasselberg.

The problem of assigning to each chemical element its definitive emission spectrum has been carried perceptibly nearer to its solution, since the necessary basis was established by the classical work of Rowland. Yet when the attempt is made to extend it to the fainter radiations, as well as to the principal lines of the spectrum, the question becomes complicated to such an extent that an exhaustive solution seems to be well nigh hopeless. It is therefore necessary, in this department of spectroscopic research, to be contented with a series of approximations; and no very great surprise need be felt if in a single case, where every effort has been made to eliminate such impurities as were most likely to occur, other impurities have been encountered, the presence of which there was in the beginning scarcely any reason to suspect. The present lines are devoted to a preliminary account of such a case as the above.

For producing the spectrum of titanium in the electric arc I have used titanic acid in the form of rutile with materially better success than when commercial titanium was employed, since the metal burns much too quickly when introduced into the arc, and is scattered in all directions. This rutile, which was kindly obtained for me by Baron Nordenskiöld, comes from Krageröe in Norway. As in other kinds of rutile, its chief component is titanic acid, since, according to analysis of a number of varieties of this mineral,[2] the only other constituent to be expected is oxide of iron in the proportion of from 1 to 2 per cent. After eliminating the iron lines which are thus caused to appear on the spectrograms, as well as other metallic lines, whose presence was revealed by comparison with my own investigations

[1] "Ueber das Vorkommen des Vanads in den skandinavischen Rutilarten." *Bihang till Svenska vetensk. Akad. Handl.* **22**, Afd. 1, No. 7.

[2] Dana's *Descriptive Mineralogy*, 5th edition, 160, New York, 1883.

of metallic spectra and with those of Kayser and Runge, I considered myself justified in ascribing the remaining lines to pure titanium, or at least in considering that only a few isolated cases remained in which contamination by a foreign metal might subsequently be proved. The continuation of my spectroscopic researches has shown, however, that this does not entirely hold good, since among the fainter and faintest lines of my titanium spectrum there are several that doubtless belong to *vanadium*. Having obtained through Baron Nordenskiöld a large piece of this metal, which was made by Moissan of Paris in the electric furnace, I recently began a re-examination of the spectrum, and discovered several strong groups of lines in the blue and violet parts, the approximate wave-lengths of which agreed very closely with those of faint lines previously measured in the spectrum of titanium. In order to obtain a final decision on this point, the parts of the spectrum in question of vanadium and rutile were photographed in juxtaposition on the same plate, in the usual manner, and compared line by line. The result of this investigation of approximate coincidences is shown in the accompanying table.

In the first two columns of this table are given the approximate wave-lengths and intensities of vanadium lines, in the region λ 403–λ 405, for which corresponding fine lines occur on the comparison plates of the spectrum of Norwegian rutile. These lines are given, with their intensities, in the two following columns, the wave-lengths being those of my former catalogue of titanium lines. As will be seen, the coincidences are almost all exact; and hence the corresponding faint titanium lines are to be removed from the titanium spectrum as properly belonging to vanadium.

I must confess that I have been greatly surprised by this result. It will be granted, I think, that there were no possible reasons for suspecting it in advance, since vanadium has never been found in any of the numerous varieties of rutile hitherto known. Under these circumstances it seemed to me desirable to subject another kind of rutile to the same test. For this pur-

Vanadium λ	Vanadium i	Rutile I λ	Rutile I i	Rutile II λ	Rutile II i	Remarks
4033.03	1.2	——				Also a weak line in Ti.
90.70	3	90.73	1			
92.87	3	92.83	1.2			
95.60	3	95.65	1			Coincident, belong to Va. All the rutile lines are weaker on the comparison plate than here represented.
4100.00	3.4	4099.94	1.2			
05.30	3	05.31	1.2			
09.95	3.4	09.92	1.2			
12.00	4	11.91	2.3			
15 30	3.4	15.32	2			
16.65	3	16.64	1.2			
23.65	3	23.68	2.3			Divided. λ Ti > λ Va.
28.25	3.4	28.20	2			Coinc. Belongs to Va.
31.35	1	31.38	1.2			Divided. λ Ti < λ Va.
34.60	3.4	34.60	1.2			Coinc. Belongs to Va.
59.87	2.3	59.79	2.3			Divided. λ Ti [illegible] λ Va.
69.45	1.2	69.46	2			Clearly divided. λ Ti > λVa.
83.45		83.45	1.2			Probably divided. λ Ti > λ Va.
4227.95	2	27.80	2			Widely separated.
68.85	3	——	1	——	1	
71.80	3	——	1	——	1	
4330.15	3	——	1—	——	1	
33.00	3	——	1—	——	1—	All these lines occur on the rutile photographs with the observed intensities. The blanks in the columns 3 and 5 of wave-lengths indicate that these lines do not occur in my catalogue of the titanium lines. On the plates here investigated they occur with the given intensities.
41.15	3	——	1+	——	1 2	
53.05	3.4	53.01	1	53.01	1.2	
79.45	4.5	79.40	2	79.40	3	
84.90	4.5	84.85	2	84.85	2.3	
90.15	4.5	90.11	2	90.15	2	
95.40	4	——	2	——	2	
4400.75	4	00.74	1.2	00.74	2	
06.85	4.5	——	1.2	——	2	
07.90	4.5	07.85	1.2	07.85	2	
08.40	4	08.39	1.2	08.39	2+	
08.65	4.5	08.70	1.2	08.70	2+	
16.65	3	16.70	2	16.70	2	Clearly divided. λ Ti > λ Va.
41.90	3.4	41.86	1.2	41.86		Perhaps. λ Ti > λ Va.
44.40	3.4	44.41	3	44.41		Probably divided. λ Ti > λ Va.

pose Swedish rutile from Käringbricka in Westmanland was chosen, one reason among others for doing so being that the results of Ekeberg,[1] according to which this particular kind also contains chromium, could be tested at the same time. A double exposure to the spectrum of this mineral and of vanadium in the region λ 425 – λ 445 having been made, the same series of coincidences was found as in the case of the Norwegian rutile (see the fifth and sixth columns of the table), and hence at the same

[1] *Sevenska vetensk. Akad. Handl.* **46**, 1893. Dana's *Mineralogy*.

time the fact was demonstrated that Swedish rutile also contains vanadium.

If, further, the observed intensities of the vanadium lines which occur in the photographic spectra of the two kinds of rutile are compared, it will be seen that the intensities for rutile II, obtained at Käringbricka, are greater throughout the spectrum than those for rutile I. Since this fact appears to indicate that Swedish rutile contains a greater amount of vanadium than Norwegian, it was of interest to test the relation of the two varieties in this respect by a special experiment, in which the exposure and development were exactly the same. With this object two exposures in the upper region of the spectrum were made on the same plate, using for each a different half of the slit, with electrodes which in one case were made of Norwegian and in the other case of Swedish rutile. The exposure was in each case 1.5 minutes. The developed plate showed the titanium lines with identically the same intensity in both spectra, while the vanadium lines were considerably stronger in the spectrum of the Swedish rutile. In order that this fact may be clearly brought out, I have made the accompanying photographic copy of a drawing,[1] in which the appearance of the negative under the microscope of the measuring engine is represented with all possible exactness. It will be seen that vanadium lines of the Norwegian rutile have a distinctly lower intensity, so that in fact some of the weakest of them fail to appear.

From what has been given above, I believe that it may be regarded as proved that both kinds of rutile contain vanadium, the Norwegian as well as the Swedish, but that the Swedish variety contains a considerably greater amount of this metal than the other. Whether this amount of vanadium is great enough to be recognized or quantitatively determined by ordinary chemical analysis is a question for the solution of which the above experiments afford no data, or at least only such as are highly uncertain, for we have as yet no trustworthy information as to the sensitiveness of the spectral reactions of the elements.

[1] Not reproduced in this JOURNAL.

On the plates which contain the spectra of the two kinds of rutile, the correspondence of lines (leaving out of consideration the difference of intensity of the vanadium lines already mentioned) is complete, with one exception. This exception is found in three quite strong lines which occur in the spectrum of the Swedish rutile, but of which there is scarcely a trace in the other variety. By referring their positions to neighboring titanium lines I obtained for these lines the following wave-lengths:

$$\lambda = 4254.50$$
$$74.90$$
$$89.90$$

while the strongest lines in the whole chromium spectrum have, according to my earlier measures, the wave-lengths

$$\lambda = 4254.49$$
$$74.91$$
$$89.87$$

The lines therefore belong to chromium, the presence of which is thereby demonstrated, and this result is in agreement with the analysis of Ekeberg.

A NEW FORMULA FOR THE WAVE-LENGTHS OF SPECTRAL LINES.[1]

By J. J. Balmer.

Since the wave-lengths of lines in the simple spectrum of hydrogen can be represented with surprising accuracy by a simple formula, it was to be expected that a formula could also be found for the spark spectra of other elements, which would be capable of representing their wave-lengths in a satisfactory manner. Professor E. Hagenbach-Bischoff has been kind enough to send me information from time to time concerning the researches and experiments that have been made in this direction. It is first to be noted, that the spectrum of any metal, as for example lithium or thallium, does not exhibit merely a single series of regularly ordered lines, but several such series, which are in general superposed, and thereby so confused that the lines of the different series appear to be jumbled together without law or order. The circumstance that the lines belonging to any one series have a certain characteristic appearance, so that the lines of one series may be sharp, those of another diffuse on the side toward the red, and those of still another diffuse toward the opposite side, makes it possible to unravel the complex of series; and when this is done it is found that every series approaches with continually narrowing line-intervals a definite and characteristic limit which lies toward the side of shorter wave-lengths. In approaching the limit the lines also become gradually fainter and more indistinct, and thus the difficulties of exact measurements are increased. Professors Kayser and Runge[2] of Hannover, who have investigated the spectra of a great number of elements with extraordinary accuracy and astonishing diligence, and have measured the wave-lengths of the lines in their series, have

[1] "Eine neue Formel für Spectralwellen." *Verhand. d. Naturforsch. Gesell. Basel, Band* 11, *Heft* 3.

[2] "Ueber die Spectren der Elemente." Berlin, 1888 *et seq.*

shown that the oscillation-frequencies, which are inversely proportional to these wave-lengths (or instead of them the reciprocals of the wave-lengths), can be represented by an algebraic series with descending powers of n^2, and that the first three terms of such a series suffice to represent the line series with a very close approximation to the numerical values deduced from observation; the longest and shortest waves perhaps excepted. For determining the three constants in this approximate formula only three oscillation-frequencies determined by measurement are required, for which the numbers n expressing the order must also be known. (For the longest possible wave this number always $= 3$.) The formula itself is, when the reciprocal of the wave-length λ_n is represented by τ_n,

$$\tau_n = A - \frac{B}{n^2} - \frac{C}{n^4}.$$

For representing the longest or at most the two longest waves, the above formula of three terms is not sufficiently accurate, and for this purpose it would be necessary to determine a fourth or fifth constant; but the values of such additional constants would be highly uncertain, since with our present means it is not possible to measure the wave-lengths with sufficient accuracy. (The accuracy at present attainable is about $\frac{1}{100000}$ of a wave-length.) The very simple formula of Kayser and Runge is of the highest value for testing and checking the results of measurement on account of the ease with which the constants can be determined, as it requires merely the solution of an equation of the first degree with three unknown quantities, and it has also served in part to determine the components of the different series. But it cannot be regarded as the real expression of the natural law governing the phenomena of the spectrum. Although the formula as used in practice has only three terms, it is nevertheless to be regarded as a finite or closed function whose denominator contains two terms, developed into an infinite series; and only after we should have succeeded in ascertaining what this closed function is, should we possess the basis for a correct explanation of spectral phenomena. It is

further to be noted that the three constants in the abridged formula of Kayser and Runge do not stand in any demonstrable relation to one another, although the second constant, in any one case, differs by only a few per cent. from a constant mean value.

I have lately made many experiments, which were often abandoned and again renewed, having for their object the discovery of such a closed expression, and in this work the friendly interest of Professor Hagenbach was a constant incentive to effort when there seemed to be no hope of success.

A first short opportunity for examining Messrs. Kayser and Runge's results led me to experiment upon the first line-series of two metals, lithium and thallium, in order to ascertain the most certain method of arriving at a solution of the problem. I observed as a consequence of performing the computations connected with this work, that if the differences of a series of wave-lengths are formed, the quotients obtained by dividing each of two adjoining differences by the next succeeding difference, form a series which answers the requirements almost exactly, and which has the extremely simple form $(n+2):(n-1)$. It is only in the case of the greatest wave-lengths that the error becomes fairly considerable. The law of the series of hydrogen lines is quite accurately represented by the formula:

$$Q_n = \frac{(2n-1)\cdot(n-1)\cdot(n+3)}{(2n+1)\cdot(n+1)\cdot(n-3)},$$

in which the lines λ_{n-1}, λ_n, λ_{n+1} are used in forming the differences. Now, on comparing the corresponding quotients for thallium with those for hydrogen, the striking fact appears, that the two corresponding series do not cover one another, but that one of them appears to be intermittently inserted between the figures of the other. This fact leads to the conjecture that in the true closed formula of the spectrum the integral number n is increased by the addition of some fraction, which is, perhaps, constant. Thus I arrived at the conclusion that the mixed number $n+c$ should be introduced into the formula instead of the integer n, in order to obtain the formula for other elements, and in this way arrived at the expression:

OBSERVED AND COMPUTED WAVE-LENGTHS OF HELIUM LINES.

	Series I α and β			Series II			Series III α and β		
	α computed from lines 1, 3, 9. β computed from lines 1, 3, 7. α: $a=3420.96$, $b=3.758942$, $c=1.999392$ β: 3420.99, 3.756648, 1.998615			Computed from lines 1, 4, 7. $a=3120.797$ $b=3.427311$ $c=2.011946$			α computed from lines 1, 3, 5 β computed from lines 1, 3, 5. α: $a=2599.342$, $b=2.871562$, $c=1.942689$ β: 2599.317, 2.869745, 1.941889		
n	O.	C.	Diff.	O.	C.	Diff.	O.	C.	Diff.
1	5876.206	5876.206	0.	5015.73	5015.73	0.	3888.97	3888.97	0.
	5875.883	5875.880	−0.03				3888.76	3888.76	0.
2	4471.85	4471.870	+0.02	3965.08	3965.031	−0.049	3187.98	3188.313	+0.333
	4471.66	4471.610	−0.05	3964.84		+0.191	3187.83	3188.115	+0.285
3	4026.52	4026.523	+0.003	3613.89	3613.872	−0.018	2945.57	2945.57	0.
	4026.35	4026.350	0.	3613.78		+0.092	2945.42	2945.42	0.
4	3819.89	3819.891	+0.001	3447.73	3447.73	0.	2829.32	2829.406	+0.086
	3819.75	3818.770	+0.02				2829.16	2829.286	+0.126
5	3705.29	3705.247	−0.043	3354.7	3354.635	−0.065	2764.01	2764.01	0.
	3705.15	3705.16	−0.01				2763.91	2763.91	0.
6	3634.52	3634.451	−0.069	3296.9	3296.817	−0.083	2723.3	2723.302	+0.002
	3634.39	3634.39	0.						
7	3587.54	3587.461	−0.079	3258.3	3258.300	0.	2696.5	2696.153	−0.347
	3587.42	3587.42	0.						
8	3554.5	3554.59	+0.09	3231.3	3231.276	−0.024	2677.1	2677.101	+0.001
		3554.56	+0.06						
9	3530.6	3530.65	+0.05	3213.4	3211.565	−1.835			
		3530.63	+0.03						
10	3512.6	3512.66	+0.06						
		3512.65	+0.05						
11	3498.7	3498.78	−0.08						
		3498.78	+0.08						
12	3487.8	3487.85	+0.05						
		3487.85	+0.05						
13	3479.2	3479.09	0.11						
		3479.09	+0.11						

$$\lambda_n = a\frac{(n+c)^2}{(n+c)^2-b}\text{; or, } \tau_n = A - \frac{B}{(n+c)^2}.$$

I first tested this formula on the series I of lithium. Previous experiments had shown that for this element the constant a is about 2300 tenth-meters. With the value 4 for b, the value determined for c was 0.72332, and with these constants the computed wave-length of the second line at λ2741.39 was 2802, or about 60 units too great. For $a=2300$ and $b=3$ (instead of 4), and with the corresponding value $c=0.2245$ deduced with their

OBSERVED AND COMPUTED WAVE-LENGTHS OF HELIUM LINES.

	Series IV.			Series V α and β			Series VI.		
	Computed from lines 2, 3, 4. $a=3678.613$ $b=4.042545$ $c=2.000229$			α computed from lines 2, 5, 8. β computed from lines 2, 5, 8. α: $a=3421.275$, $b=3.746843$, $c=1.696996$ β: 3421.109, 3.747853, 1.697826			Computed from lines 1, 4, 7. $a=3679.022$ $b=4.027016$ $c=1.852937$		
n	O.	C.	Diff.	O.	C.	Diff.	O.	C.	Diff.
1	6678.1	6677.5	−0.6	7065.77* 7065.51*	7055.86 7054.83	−9.91 −10.68	7281.8	7281.81	+0.01
2	4922.08	4922.08	0.	4713.39 4713.17	4713.39 4713.17	0. 0.	5047.82	5048.529	+0.709
3	4388.11	4388.11	0.	4121.15 4120.98	4121.196 4121.047	+0.046 +0.067	4437.73	4437.859	+0.129
4	4143.91	4143.91	0.	3867.77 3867.61	3867.790 3867.652	+0.02 +0.042	4169.12	4169.12	
5				3733.15 3733.01	3733.15 3733.01	0. 0.	4024.14	4024.083	−0.057
6				3652.29 3652.15	3652.261 3652.118	−0.029 −0.032	3936.1	3936.051	−0.049
7				3599.59 3599.45	3599.588 3599.443	−0.002 −0.007	3878.3	3878.3	0.
8				3563.26 3563.11	3563.26 3563.11	0. 0.	3838.2	3838.237	+0.037
9				3536.9	3536.946	+0.046	3808.3	3809.256	+0.956
10				3517.5	3517.452	−0.048			
11				3502.5	3502.530	+0.03			
12				3490.8	3490.839	+0.039			
13				3481.5	3481.514	+0.014			

* Phot. (sic). This line was measured optically. *Ap. J.*, **3**, 7. Eds.

aid, the computed wave-length of the second line was 2764.76 or still too great by 23.37 units. A third trial with $b=2.5$ made $c=-0.05646$ and the second wave-length 2740.56, thus only 0.83 units too small. The computation when extended to the following lines, with the constants last determined, gave results which in the average deviated by only about one-fourth of a unit from the measured wave-lengths. Since only round numbers were used for the first and second constants in this first trial of the new formula, I was greatly surprised at the close agreement of the result, and the

conviction fastened itself upon me that this formula was an adequate expression of a physical truth.

Professor Albert Riggenbach remarked to me, on the occasion of an incidental meeting, that Professors Runge and Paschen had published extremely accurate measures of the lines of helium,—an element which was first discovered in the chromosphere and in some of the Orion stars, but which had not been found in terrestrial substances until very lately, when it was found to exist as clèveite gas in certain minerals,—and he suggested that these measurements would in all probability be very suitable for testing the closed formula. The next day he sent me the figures for the three double series and the three single series of helium lines, according to the communication of Runge and Paschen,[1] and an account of the lines in clèveite gas ascribed by Lockyer to helium, together with the complete general solution of the equation of the third degree with three unknown quantities which is implied in the formula. I here desire to extend my best thanks to Professor Riggenbach for his kind assistance, hints, and communication of facts. The figures which he sent me have been used in my computations, and the results which I have found are exhibited in the tables given above. In the double series, I, III and V, Runge and Paschen have not represented the shortest pairs as divided, no doubt because these pairs are too close and too faint for exact observation. The numbers given for them have therefore one decimal place less than the double lines of the series.

In computing the constants the choice of the lines on which the computation is based has a very great influence on the result, particularly in the case of the longest waves. If, on account of small errors of observation, the adopted values of the wave-lengths differ even very slightly from the true values, the computation of the constants is considerably affected, and this influence is most felt in the greatest wave-lengths with smallest values of n,—not so much through the influence of the con-

[1] *Mathem. u. Naturw. Mittheilungen d. K. preuss. Akad. Wiss.*, Berlin, 323, 377. 1895.

stants a and b as through that of c. When therefore the computed values obtained with the formula are found to deviate here and there from the results of observation, in the case of the longest waves of a series, this fact may be ascribed to the great difficulty of determining the constants, rather than to deficiencies of the formula. It is presumable that in series where observation and computation are at variance in the greatest wave-lengths, complete agreement could be brought about by a suitable change in the constants.

Testimony in favor of the closed new formula is found in its simplicity, which is only equaled by that of the accepted hydrogen formula, and further in its intimate relation with the latter, which is only a special form obtained from the new formula by placing $b=4$ and $c=0$. Still another advantage of the new formula seems to lie in this, that it is now a matter of indifference what integral value is given to n, so long as the lines of a series, and therefore the values of n, progress uninterruptedly; for by as much as n is taken greater or smaller, compensation to that amount is effected by the smaller or greater value of c.

With regard to the meaning of the constants, that of a is quite plain; it indicates the limiting wave-length in which the series of lines terminates. The constant c, on the other hand, indicates the displacement by which the integral values of n must be increased or diminished; a fraction which is constant for one and the same series. The least intelligible significance is that which attaches to the constant b, by which the square of $n+c$ in the denominator is diminished. This constant seems to have the character of a square quantity; for if the constant b in the typical hydrogen formula is diminished from 4 to 1, only the wave-lengths of the originally even values of n remain, and the uneven wave-lengths disappear, so that the curve of wave-lengths is reduced one-half, a change which is repeated in a corresponding manner when other quadratic values are given to b.

The constant b has a quite remarkable relation to the con-

stant a. If for any series of lines a is divided by b, a number is obtained which is equal to within about ½ per cent. to the corresponding quotient for the simple series of hydrogen. The latter quotient is $3645.6:4=911.4$. The corresponding quotient for the helium series I α and β, II and IV, is a little more than 910, and therefore about 0.1 per cent. less than for hydrogen; for series III α and β it is over 905; for series V α and β, and series VI it is nearly 913. For the lithium (single) series I a computation based on the lines 1, 4 and 7, gives for the values of the constants, $a=2299.401$, $b=2.514417$; if lines, 1, 3 and 5, are taken the values are $a=2298.643$, $b=2.536159$. The quotient of the first pair of constants is 914.48, that of the second only 906.20. The mean of the two is 910.34. As I have already remarked it is possible that such discrepancies in the values arise from the unavoidable minute errors of observation, so that a definite judgment as to the incorrectness of the formula should not be based on them. These remarkable approximations to a constant mean value do not at any rate exclude the possibility that we are here dealing with relations that are founded on fact, and that offer to us, like so many others that occur in nature, enigmas to attempt the solution of which there is always an irresistible charm.

ADDENDUM.

Through the kindness of Professor Hagenbach, who lent me the memoir of Messrs. Kayser and Runge for the purpose of more detailed study, I have had the opportunity of becoming acquainted not only with their own results, but with their highly interesting account of a formula proposed several years ago by the Swedish savant Rydberg.[1] The closed formula above given agrees almost perfectly with Rydberg's formula, the only difference being that the constant B $\left(=\frac{b}{a}\right.$ of the former), instead of having a particular value for each element, is assumed by Rydberg to have a value which is the same for all the elements.

[1] "Spectren der Elemente," 4 Heft, Nachtrag, 61.

(109721.6, or the reciprocal of 911.4 of hydrogen), and therefore equal to the corresponding constant of the hydrogen formula. It may be conjectured that Rydberg has chosen this value for the basis of his formula, because it represents the mean of the corresponding constants for all the other elements, and because this assumption greatly simplifies the computation of the two remaining constants ;—for a direct determination of all three constants from three measured wave-lengths requires the some what tedious solution of an equation of the third degree.

Messrs. Kayser and Runge have shown that the original formula of Rydberg leads to less satisfactory results than their abridged series ; nevertheless Rydberg ascribes to his own formula greater pretensions to correctness.

Kayser and Runge have further shown that even a modification of Rydberg's formula obtained by giving special values to B in his equation

$$\tau_n = A - B\,(n + c)^{-2}$$

furnishes no better results than three terms of their series of powers. But since Kayser and Runge have not described the manner in which they determined the value of the constant B, it may be assumed as probable that they have used the values of B deduced from their own formula as a basis for this modification. By this process, however, the correctness of the modified Rydberg formula, in the form which I have independently discovered, is not yet disproved; for the direct determination of the three constants in the formula

$$\tau_n = A - B\,(n + c)^{-2}, \text{ or } \lambda_n = a + \frac{b}{(n + c)^2 - b},$$

in which $A = \frac{1}{a}$ and $\frac{B}{A} = b$, does not lead to the same values of B as the formula

$$\tau_n = A - Bn^{-2} - Cn^{-4}.$$

Since the deviations of the second constant B from a mean value are comparatively small for all the elements in both formulæ, Messrs. Kayser and Runge are led to remark that "Rydberg's assumption is possibly so far correct, that in the still

hidden true law this constant represents one and the same value throughout."[1]

Rydberg found that for all elements the curve determined by erecting ordinates proportional to the wave-lengths, at equal intervals corresponding to successive values of n as abscissæ, resembles a hyperbola, since it approaches lines parallel to the axes as asymptotes.

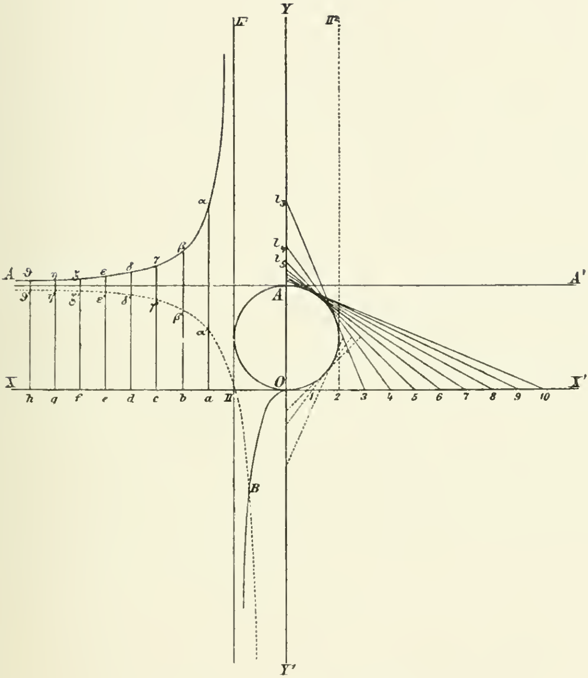
If we test the character of the curve for the simple hydrogen spectrum, where the relations are simplest and clearest, and take into account all (including negative) values of n, we shall find that the curve is of the third degree, with three asymptotes (see the figure). The single horizontal asymptote lies at the distance a above the axis of abscissæ. On each side of the axis of ordinates, parallel to the latter, and at a distance from it equal to $2n$, is a vertical asymptote. The curve itself has three branches: two of a generally hyperbolic form above the horizontal asymptote, separated from each other by the interval $4n$ between the vertical asymptotes, and a third between the vertical asymptotes, having its vertex at the origin, with infinite branches which form a transition to the hyperbolic curves above.

The curve of reciprocals of wave-lengths in the hydrogen spectrum (taking as unit $a = 4n$) is easily shown in its relations to the wave-length curve. It also is a curve of the third degree, and consists of only two branches, which as before resemble the hyperbola in form. They have the same horizontal asymptote as the wave-length curve, and a single vertical asymptote, which is the axis of ordinates. These branches pass through the intersections of the vertical asymptotes of the wave-length curve with the axis of abscissæ, and approach the axis of ordinates as asymptote below, having a cusp at infinity.

In the accompanying figure (Plate VIII) XX' is the axis of abscissæ, YY' the axis of ordinates, O the origin; AA' is the horizontal asymptote and H, H' and $2H^2$ are the vertical asymptotes; $\alpha\,\beta\,\gamma$, etc., is the wave-length curve of hydrogen; $a\alpha$ the wave-length γ_3, $b\beta = \lambda_4$, etc. The curve of reciprocals is $B\,H\,\alpha'\,\beta'\,\lambda'$.

[1] *Spectren der Elemente*, IV Abschnitt, 63.

PLATE VIII.



$\alpha\ \beta\ \gamma\ \delta\ \epsilon\ \zeta\ \eta\ \theta$: Curve of Wave lengths.
$\alpha\ \beta\ \gamma\ \delta\ \epsilon\ \zeta'\ \eta\ \theta'$: Curve of Reciprocals.

etc., $a\alpha'$ being the reciprocal of λ_3, $b\beta'$ the reciprocal of λ_4 or $b\beta$, etc. Only half of each curve is drawn; the other half may be readily supplied, the curves being symmetrical with respect to the axis of ordinates.

A very simple construction of the hydrogen wave-lengths is shown on the right side of the figure. Let OA on the axis of ordinates represent the constant a, or the lower limit of the hydrogen wave-lengths, and let a circle be described having $AO = 3645.6$ Ångström units as a diameter; then if tangents are drawn to the circle from the points $n = 1, 2, 3$, etc., on the axis of abscissæ (the unit is taken to be $1n = \frac{1}{4}a = 911.4$), their intercepts on the axis of ordinates will represent the wave-lengths.

The correctness of the construction may readily be proved.

This construction may possibly be useful in throwing a new light on the mysterious phenomena of the spectral lines, and in leading to the right way of finding the real closed formula for spectral wave-lengths, in case it has not already been found in the formula of Rydberg.

The final impression, which our mind involuntarily receives in contemplating these fundamental relations is that of a wonderful mechanism of nature, the functions of which are performed with never-failing certainty, though the mind can follow them only with difficulty and with a humiliating sense of the incompleteness of its perception.

Minor Contributions and Notes.

NOTE ON A CAUSE FOR THE SHIFT OF SPECTRAL LINES.

I WOULD call attention to a cause for the shift of the lines that Messrs. Jewell, Humphreys, and Mohler have been investigating with so much skill and success, which is allied to Professor Schuster's suggestion[1] but is so far distinct that it is not disproved by the observation that the shift is independent or largely independent of the amount of the substance in the arc.

When a body is a source of electromagnetic radiations the frequency of its vibrations depends in general on the specific inductive capacity of the medium in which it is immersed. An electromagnetic oscillator performs oscillations that can be calculated from a formula of the form $N^{-2} \propto L\ C$, where L is self induction and C is capacity. If the medium have a high electric inductive capacity C will be large and consequently N will be small. Now an increase in the pressure of a gas increases its specific inductive capacity and must in consequence alter to some extent the period of vibration of the molecules in it, if their period of vibration depends at all on electric forces due to constant charges. We can consequently conclude that here is certainly a *vera causa* for some shift towards the red in molecules causing light, for in them there can be no doubt that electric forces are at least a part of the forces affecting the periods of vibration.

We can see that the complete solution of the question from this point of view is very complex. On the molecular scale we cannot deal with a gas as a continuous medium having a definite calculable specific inductive capacity. It is a very complex question how far an average specific inductive capacity in its neighborhood would control the vibrations of an electric oscillator. It would depend on the extent to which the oscillator was or was not self contained. Now what is called the dimension of a molecule is a measure of the extent of its action on its neighbors and consequently of their reaction on it. There is consequently reason to expect that some such rela-

[1] This JOURNAL, 3, 292, 1896.

tion as has been observed should exist between the dimension of the molecule and the amount of the shift. In some of the cases I have tried there seems to be some connection between the refractive index of the gas and the amount of the shift, but I would not expect much connection of this kind to exist because the principal cause for a change in the specific inductive capacity would be the high pressure air present, which is the same in all the cases observed, and secondly because the refractive index is a measure of the average specific inductive capacity only, and from this alone we could not expect to calculate the amount of the shift in each case because, as I said, this latter will depend partly on how far this average specific inductive capacity is able to alter the vibration periods of the molecule. It is evident, for instance, from the experiments that the influence of the cause, whatever it is, on some of the calcium movements that underlie certain of the lines is much greater than its influence on other movements underlying other lines.

Everybody must feel the very greatest interest in this work. It is bringing us measurably nearer a knowledge of atomic movements and interactions, the great goal of modern physical research.

TRINITY COLLEGE, Dublin. GEORGE F. FITZGERALD.

NOTE ON A FORM OF SPECTROHELIOGRAPH SUGGESTED BY MR. H. F. NEWALL.

IN a recent number of the *Proceedings of the Cambridge Philosophical Society*[1] Mr. Newall publishes an interesting suggestion for a new form of spectroheliograph.

After describing several instruments previously employed by M. Deslandres and the writer he suggests that some modification of Littrow's spectroscope with fixed slits would seem to offer obvious advantages for these investigations. The proposed spectroheliograph consists of a single telescope, which serves as both collimator and camera, with a grating (or train of prisms) attached by means of a suitable framework at the objective end. The slits are fixed on opposite sides of the eye-end of the telescope. Light entering the first slit meets a right-angle prism near the axis of the telescope, from which it is reflected into the collimator lens. The spectrum formed by the

[1] *Loc. cit.*, 9, 179, 1896.

grating is returned through the tube, falls upon a second right-angle prism, and is brought to focus on the second slit. By simply rotating the grating any desired line may be made to pass through this slit. The solar image and the photographic plate are in parallel planes, and remain fixed in position while the spectroheliograph is moved in the direction of its optical axis. Mr. Newall suggests that such an instrument be mounted like the bob of some forms of ballistic pendulums, with the slits vertical when at rest, the first slit bisecting the solar image formed by a coelostat. It is then to be set swinging with an amplitude slightly greater than the diameter of the Sun's image, and allowed to swing long enough to give a sufficient exposure.

As Mr. Newall remarks, a spectroheliograph embodying the Littrow principle was built for the writer some years ago. Mr. Newall's proposed instrument is decidedly superior to that particular piece of apparatus, which was designed to be used under circumstances such that movement as a whole was inadmissible. Since that time exactly such an instrument as that now described was suggested by Professor Wadsworth, in the course of our discussion relative to the design of the large spectroheliograph for the 40-inch refractor of the Yerkes Observatory. The plan of suspending the instrument like a pendulum, which was considered by the writer when the spectroheliograph belonging to the late Mr. Ranyard was being designed, was abandoned for the reason that the first slit would not remain parallel to itself during the exposure if the instrument were mounted in this way. Thus the lines in the photographed solar image which are due to dust on the slits would be curved instead of straight, and it would be troublesome, in measuring the photographs, to apply corrections necessitated by the curvature of the spectral lines. The distortion due to this curvature, while very considerable with prisms, is also by no means inappreciable with gratings. To remove this difficulty Professor Wadsworth has suggested that the spectroheliograph be suspended on some system of link-work giving a parallel motion. In this form it could be used to good advantage with a coelostat, though I am not sure that equally good results could not be secured with an instrument carried by ball bearing wheels rolling on rails.

After using many different forms of spectroheliograph, the writer is of the opinion that the type represented by the Ranyard instrument is probably as good as any other, at least for use in an invariable plane. For some reasons it would be of advantage to insert two right-angle

prisms, as Mr. Newall suggests, in order to make the motion parallel to the axis of the collimator, and to give more room for the photographic plate holder, or the camera box used with an enlarging lens. But it would probably be better to avoid the Littrow form, in spite of its simplicity, rigidity and compactness, unless the difficulties due to scattered light can be eliminated. It is true, as Mr. Newall remarks, that the central reflections can be partially or wholly stopped out, but the fact remains that the objective is illuminated by the sunlight passing through the first slit, and it is difficult to protect the sensitive plate from the scattered light.

The principal objection to the type of spectroheliograph just referred to is the considerable mass of the moving parts. This is not very serious when the instrument is used with a heliostat or coelostat, where it can easily be counterbalanced. But when it must be attached to the eye end of an equatorial the difficulties are much greater. For this reason experiments are now being made at the Yerkes Observatory to test one of the ingenious forms of moving slit suggested by Professor Wadsworth.[1]

It should be added that the spectroheliograph, whether used with an equatorial or a coelostat, should be so mounted that it can be rotated in position angle. Considering the distortion due to curvature of the spectral lines, which is inevitable in all forms of the instrument hitherto constructed,[2] it is a matter of some practical importance to be able to place the slit parallel to the Sun's axis before making an exposure.

Mr. Newall's suggestion that the spectroheliograph be made to move rapidly across the Sun's image several times during a single exposure seems to me a good one. Images free from the very objectionable lines due to inequalities of motion could undoubtedly be obtained in this way. The suggested pendulum support would be very convenient for exposures of this kind, but it may be doubted whether this advantage would offset the disadvantages already mentioned.

It is to be hoped that Mr. Newall will decide to have constructed a spectroheliograph embodying some of the new ideas.

George E. Hale.

Yerkes Observatory,
February 1897.

[1] This Journal, 1, 244, 1895.

[2] Mr. W. H. Wright, of the Yerkes Observatory, has suggested a method of correcting this distortion.

NOTE ON STEADY LIQUID SURFACES.

In some experiments carried out in the spring of 1894 in which it was necessary to obtain a sharp image of a line by internal reflection from a liquid, it was found impossible to use a polished glass surface of sufficient extent placed in contact with the liquid. It became necessary to test the conditions for damping of earth tremors and air disturbances.

Of several piers, one was selected showing the least disturbance on a mercury surface. Such a liquid surface, when the containing vessel was placed upon a thick layer of felt on a pier, showed most marked tremors at any time of night when local street traffic had ceased. A 4-inch collimator and telescope at an angle of 60° or more incidence and with the eyepiece removed, showed in a most interesting way the ripples produced by a switch engine three-quarters of a mile away in the dead of night. With the eyepiece in, the image of the slit appeared fairly sharp. A second float containing mercury, placed on the first surface, showed nearly the same effect. A water surface upon this showed the same. The ripples did not originate at the edge of the surface much of the time.

An attempt was then made to destroy the tremors by greatly increasing the inertia of the support, by piling up for a couple of feet alternate layers of thick felt and iron, weighing several hundred pounds. With the mercury surface resting upon this, and with the eyepiece of the telescope removed, ripples, arising from tremors, could still be seen under the most favorable circumstances.

Heavy masses supported by elastic means of different kinds showed the ripples still. A pneumatic arrangement gave the most promise, as evidently here, if the reservoir is large and the supporting area small, the transmitted changes of pressure can be almost eliminated; but in all cases of springs supporting masses, short period tremors seemed to be communicated through the spring itself and the envelope, in the case of air.

A different arrangement was then tried with success, consisting of four boxes fitting within one another with a clear space of from one to two inches between them. The outer one, about 50 × 10 × 10 inches, was placed upon felt layers on the pier, and the space between it and the next filled with cylinder oil (medium). The second was ballasted with iron and the third placed within it upon layers of cotton. The

space between three and four was likewise filled with oil. Number four was ballasted and a support for a tube was placed within it on cotton layers. The whole arrangement was protected from air disturbances.

A horizontal tube, 50×2 inches, with capped ends and partly filled with water, showed no evidence of ripples under favorable circumstances. A telescope of 1-inch aperture and an angle of incidence of 89°, so that the light was incident over the full length of the surface, showed a resolving power of about $1''$ for 1-inch aperture, the calculated limit. Of a number of different liquids, used without jacketing the tube, water was the only one which gave for internal reflection for this length of tube, clear definition. All gave good definition for external reflection. With mercury and water upon mercury the full resolving power of the telescope was obtained.

The results indicate that there is more chance of transmitting rapid vibrations through elastic supports than through very viscous floats. Elastic supports for masses of great inertia may protect from slow disturbances as well as floats, but the latter seem to damp all vibrations most completely.

Position and steadiness can be obtained, if necessary, by a light packing of cotton in the surface of the oil. This was found not to affect the result in definition. Little was gained by making the thickness of the layer of oil large. A viscous liquid was found much superior to any other, such as water or mercury, as the ripples in the latter are not damped rapidly enough, and communicate disturbances. Of course everything must be protected from air currents, particularly the surface to be observed, as these are some of the chief disturbing elements.

D. B. BRACE.

AWARD OF THE GOLD MEDAL OF THE ROYAL ASTRONOMICAL SOCIETY TO PROFESSOR BARNARD.

I TAKE great pleasure in announcing that the Royal Astronomical Society has awarded the gold medal to Professor E. E. Barnard, Astronomer of the Yerkes Observatory, for his contributions to astronomical science. These include his discovery of the fifth satellite of Jupiter, micrometric measures of planets, asteroids, satellites, nebulæ, and comets, numerous discoveries of comets, photographs of the Milky Way, comets, nebulæ, and other objects with a portrait lens, and other

important observations. All of his colleagues at the Yerkes Observatory unite in extending to Professor Barnard their heartiest congratulations upon this well-deserved recognition of his work.

GEORGE E. HALE.

ON THE MODE OF PRINTING MAPS OF SPECTRA.

THE following remarks are quoted from the report in the February *Observatory* of the discussion at the meeting of the Royal Astronomical Society on January 8. They are of interest in connection with Professor Kayser's proposal that the mode of printing maps and tables of wave-lengths, adopted by the Board of Editors of this JOURNAL in 1895, should be reversed.[1] Further expressions of opinion will be gladly received by the editors for publication in the ASTROPHYSICAL JOURNAL.

The order of decreasing wave-lengths has been followed throughout; and I much regret that many astrophysicists have recently decided to follow the reverse order of the pianoforte keyboard in the order of the spectrum lines. *Rev. W. Sidgreaves.*

I was extremely pleased to hear Father Sidgreaves' opinion as to the place in which the red end of the spectrum should be drawn, because, like himself, I am a heretic on that point. The ASTROPHYSICAL JOURNAL has laid down the law that the red end should be to the right, but I think the whole analogy is the opposite way. I showed some slides of the spectrum of helium here some time ago, and in those slides the red end was put to the left, and this arrangement was criticised; but it was necessary it should be so, because I was dealing with the question of series of lines, and it seems to me we can only deal with a series of lines by beginning with the left end, in the same way as we begin on the left-hand side of the page of a book. There is also the analogy of the piano. I shall be glad to see a reversal of the decision of the ASTROPHYSICAL JOURNAL. *Mr. Maunder.*

I think they are reopening the question. — *Mr. Newall.*

The delineation of the spectrum from left to right in accordance with the increase of wave-lengths was adopted by Kirchhoff, Thalén, and Angström, also by Huggins, Lockyer, Cornu, Dunér, Draper, Pickering, Rowland and others. — *Mr. McClean.*

On the subject of the arrangement of spectrum lines referred to by Mr Maunder, Mr. McClean, and Father Sidgreaves, I think that for the proper

[1] See this JOURNAL, 4, 306, November 1896.

representation of the spectrum scale the small wave-lengths ought, as in the high keys of a pianoforte, to be placed on the right.

—*Prof. Alexander Herschel.*

SALE OF INSTRUMENTS AND DRAWINGS FROM THE COLLECTION OF THE LATE M. TROUVELOT.

We desire to call attention to the fact that the following instruments and drawings, which belonged to the late M. Trouvelot, of the Observatoire de Meudon, are now offered for sale by his family.

(1) A photographic telescope with enlarging apparatus, especially designed for solar photography. The object glass, by Brashear, is of 15^{cm} clear aperture and $200^{cm}.8$ focal length, and is corrected for the region near G. The tube and other metallic parts are by Bardou of Paris. A brass dew-cap 50^{cm} long, provided with hinged cover, forms part of the instrument. The telescope tube is perforated by two openings 180° apart, for the purpose of allowing both sides of the objective to be brought to the same temperature. The tail-piece carries a tube moved by rack and pinion, with scale and vernier for accurate setting. There are two amplifying eyepieces by Brashear. No. 1 gives an image of the Sun 100^{cm} in diameter at a distance of 100^{cm}. No. 2 gives an image 20^{cm} in diameter at a distance of about 50^{cm}. The photographic camera attached to the lower end of the tube is provided with all necessary adjustments, and is designed to carry a plate $25^{cm} \times 25^{cm}$. It contains a special curtain-shutter for giving very short exposures. The adjustable slide in the curtain can be given any opening up to 1^{cm}. Attached to the telescope is a Secretan finder, with an eye-piece which projects the solar image upon a ground-glass supported in a brass cone. The price of this instrument complete is 5000 francs.

(2) A comet seeker of 10^{cm} clear aperture and 145^{cm} focal length. Near the center of the tube a large right-angle prism is mounted so that the observer always looks in a horizontal direction. The mounting is in the alt-azimuth form, and a hand wheel is provided for moving the telescope, which is suitably counterbalanced. A metal strap with pivot is so arranged that the instrument can be mounted upon a suitable column. The metal work of the tube is of polished and lacquered brass. A low power (Clark) eyepiece accompanies the telescope, which is offered for 1500 francs.

(3) The original pastel drawings of various astronomical objects made by the late M. Trouvelot. Many of these are familiar through the reproductions published in the United States, where the drawings were made.

For further information, intending purchasers should address M. Georges H. E. Trouvelot, 23, rue des Capucins, Meudon, Seine et Oise, France.

ERRATA.

The following corrections should be made in Mr. Jewell's article in the December 1896 number of this Journal:

Page 328, for *amplitude* read *azimuth*.

Page 335, Table IV, for βm read m.

Reviews.

Ueber einen Versuch eine electrodynamische Sonnenstrahlung, und über die Aenderung des Uebergangswiederstand bei Berührung zweier Leiter durch electrische Bestrahlung: J. Wilsing und J. Scheiner. *Wied Ann.* **59**, 782–792, 1896.

At the Astrophysical Observatory in Potsdam, Messrs. Wilsing and Scheiner have been making a careful search for the presence of long electromagnetic waves in the solar radiation. It was, from the outset, expected that, if such waves were emitted by the Sun at all, their intensity would be greatly diminished on passing through the Earth's atmosphere.

The determining factor, therefore, in the selection of a detector was *sensibility*. Accordingly Lodge's form of Branly's Coherer, a "bridge" of three steel wires, was selected. Of these three wires, two are laid parallel and the third is laid across the two; the battery and galvanometer are joined in series with the bridge thus formed. The whole was then placed in a metal case to shield it from outside disturbances. In the top of this case was an opening fitted with a metallic reflector, which could be used to direct any desired radiation upon the "bridge." This simple and extraordinarily sensitive instrument proved itself much like other sensitive instruments, viz., unreliable in its very small indications. A heliostat fitted with a metallic mirror directed the solar radiation toward the receiver. Two paper screens, transparent to long waves, kept out the heat and light.

As to results, nothing positive was attained. The indications due to solar radiation, if any, were less than the errors in reading the galvanometer scale.

This interesting attempt to extend the solar spectrum reminds us of a fact which cannot be over-insisted upon at this time, viz., there is a very wide difference between assuming on mathematical grounds and proving by experiment, the continuity of the properties, or even of the existence, of all waves intermediate between the very short ones photographed by Schumann and the very long ones studied by Hertz.

H. C.

Total Eclipse of the Sun, April 16, 1893. Report and Discussion of the Observations relating to Solar Physics. By J. NORMAN LOCKYER, *Phil. Trans.*, **187**, pp. 551–618, 1896.

THE exceedingly interesting and important results obtained by Mr. Shackleton at the eclipse of last August in photographing the spectrum of the "flash" immediately preceding totality, have directed attention to the important part played by the prismatic camera in eclipse observations. The results secured by Mr. Shackleton will be described and illustrated in a subsequent number of this JOURNAL. At present we must confine our attention to the almost equally valuable results obtained by Messrs. Fowler and Shackleton at the eclipse of April 16, 1893. The reports of Messrs. Fowler and Shackleton, together with a discussion of the results by Professor Lockyer, are contained in a memoir recently published in the *Philosophical Transactions.*

The memoir opens with an introductory statement by Professor Lockyer, in which a brief historical sketch of the use of the prismatic camera in earlier eclipses is given. In 1871 Respighi and Lockyer first used this instrument for eclipse work. Previous to this time it had been employed by Fraunhofer in his early observations of the spectra of the stars, and later by Secchi in his stellar spectroscopic work and by Respighi in certain special observations of the Sun. In 1871 Resphigi used a single prism over the object-glass of his telescope, and Lockyer employed a train of five prisms without either collimator or observing telescope. At the beginning of totality Respighi saw the chromosphere in the lines C, D_3, F and G, and later three bright rings, which he considered to correspond with C in the red, 1474 in the green, and F in the blue. Of these the green ring was the brightest, most uniform, and best defined. Lockyer's observations were made 80 seconds after the beginning of totality. He saw the C ring very bright, 1474 and G faint, and F of intermediate intensity.

In 1875 photography was first employed in eclipse work with the objective prism, but the dispersion was so small that the results were of no great value as compared with those subsequently obtained. In 1878 no bright rings were recorded. In 1882 Dr. Schuster photographed a green ring corresponding to 1474, and a yellow one which he believed to coincide with D_3. In 1883 the same instrument used in the preceding year was employed, but gave no valuable results. The same camera was again employed in 1886, and recorded the spectra of

some prominences, but apparently gave no rings. In 1893 prismatic cameras were used by Messrs. Fowler and Shackleton, and with them photographs were obtained which are far superior to those secured at previous eclipses.

The prismatic camera used by Mr. Fowler at Fundium, West Africa, was one which had been in constant service at South Kensington for stellar spectroscopic work. It consists of a single prism of 45° refracting angle, supported at the position of minimum deviation in front of a photographic objective of 6 inches aperture and 7 feet 6 inches focal length. The correction of the object-glass, which is by the Brothers Henry, is such that the whole spectrum is in focus when the plane of the plate is normal to the axis of the camera. With the dispersion of the single prism the spectrum is about two inches long from H to K. The rings corresponding to the inner corona have a diameter of about seven-eighths of an inch. The objective and prism were mounted at the end of a strong mahogany tube of square section, which was attached to the declination axis of a 6-inch Cooke refractor. The plate holders were divided into three compartments, each taking a plate 4 by 6 inches. Between each exposure the slide was pushed forward so as to bring a fresh plate into position. The exposures were made by covering and uncovering the prism with a piece of thick card. During the eclipse thirty photographs were taken, with exposures ranging from "instantaneous" to 40 seconds. Six of these were made before and nine after totality.

At the Brazilian station Mr. Shackleton employed a prismatic camera consisting of a large photographic spectroscope deprived of its collimator, mounted on an iron table, in conjunction with a 12-inch siderostat. The optical train consisted of two 60° prisms of 3 inches aperture, and a Dallmeyer portrait lens of 3.25 inches aperture and 19 inches focal length. With this camera the length of the spectrum was 1.65 inches from $H\beta$ to K and the diameter of the Sun's image 0.176 inch. Each of the plate holders, of which three were provided, contained eight compartments for plates. These were successively brought into position by means of a rack and pinion. Twenty-four exposures were made, ranging in length from "instantaneous" to 60 seconds. Of these one was made before totality, and six after the end of the total phase.

The appearance of the photographs obtained in Africa is illustrated by the accompanying cut, reproduced from a positive on glass of one

of the photographs which was kindly presented to the reviewer by Mr. Fowler. It is seen that the chromosphere and prominences are remarkably well shown in a large number of rings. Of these, by far the brightest are those due to H and K, while the hydrogen rings are second to these in intensity.

In the photographs taken about mid-eclipse, some of which are reproduced in Professor Lockyer's memoir, the spectrum of the chro-

mosphere is not shown on account of the central position of the Moon. Such prominences as were high enough to be seen beyond the Moon's limb are represented in the photographs. One of the negatives faintly outlined a bright group of prominences in the *Hα* line, although the plates were not very sensitive in this part of the spectrum. Images of the prominences in D_3 were also shown. The spectrum of the corona appears from these negatives to be largely continuous, but some of the photographs show a nearly complete ring corresponding to 1474, and small portions of very faint rings. The continuous spectrum is brightest near the photosphere and fades out very gradually away from the limb. Little can be determined from these photographs regarding the wavelength of the point of greatest intensity, without a careful study of the curves of sensitiveness of the plates employed. On the ordinary plates, the position of maximum intensity is about $\lambda 450$, while on the isochromatic plates there is another maximum about $\lambda 560$. At these points the continuous spectrum extends farthest from the photosphere, on three of the plates reaching a distance of about two-thirds of the Sun's diameter.

The 1474 ring is shown in four photographs, one of them made on ordinary and three on isochromatic plates. This ring reaches its greatest height some 45″ above the Moon's limb, on a plate made about the middle of totality with an exposure of 40 seconds. The variation of the intensity of the ring is very marked, as it is clearly visible near the poles and quite bright in the equatorial regions. The position of

greatest brightness corresponds closely with the brightest regions in the direct photographs of the corona. The ring seems to have no connection with those due to the prominences, and there was no trace of the 1474 line in the spectrum of any of the prominences The memoir does not state that the 1474 ring showed any trace of structure corresponding to the rays and streamers shown in the direct photographs of the corona.

In addition to 1474 several fainter coronal rings are shown, which can be easily distinguished from the rings due to the chromosphere and prominences, as their points of maximum luminosity never coincide. Moreover, the chromosphere rings are sharply defined, while those due to the corona are hazy and indistinct. The intensities of these rings fall off rapidly in going outward from the Sun's limb. On account of the short focal length of the object-glass used in Brazil, the images of the coronal rings obtained with it are much brighter than those photographed in Africa. The Brazilian negatives taken about the middle of totality give the 1474 ring with great intensity and sharply defined outline. A comparison of this ring with Professor Schaeberle's photographs of the inner corona shows that the brightest parts of the ring correspond with the brightest parts of the corona, where the continuous spectrum is most intense.

The reviewer has previously had occasion to refer to these same photographs in discussing the nature of the so-called "white prominences."[1] They admirably illustrate the differences in the intensities of lines in the spectra of various prominences. In certain cases prominences are shown in the H and K lines which are either extremely feeble or altogether lacking in the hydrogen lines. Thus we have certain proof that prominences exist, which when seen with the naked eye would have rather a lilac than a red color. As has been pointed out in the paper just referred to, the "white prominences" observed by Tacchini and others can probably be explained in this way.

In Part II, which consists of a discussion of the observations, Professor Lockyer first considers the relative advantages of the slit and slitless spectroscopes for eclipse work. With the former, lines lying close together are less likely to be confused through overlapping of the images, feeble lines have a better chance of being recorded, and the dark lines due to reflected sunlight in the corona can be shown. The prismatic camera, on the other hand, gives results which are at the

[1] This JOURNAL, 3, 374, 1896.

same time pictures of the various phenomena and images of their spectra. The prominences are shown in their proper positions, and their radiations are not confused with those of the corona. The light of the prominences and corona, scattered by our own atmosphere, instead of producing false lines in the spectrum, as in the case of the slit spectroscope, is practically eliminated by the prismatic camera. Further, as is also the case with stellar spectra, there is a considerable saving of light due to the absence of the slit and lenses used with the slit spectroscope. As the results recently obtained by Mr. Shackleton best illustrate, the prismatic camera is admirably adapted for photographing the "flash" at the beginning or end of totality. If the slit spectroscope were used for this purpose, the adjustments would have to be made with extreme care in order to obtain similar results, while with the slitless instrument no special adjustments are required.

The coronal rings photographed with the prismatic camera, with the exception of that belonging to 1474, are very feeble, and their wave-lengths cannot be very accurately determined. On the African photographs eight rings of this kind were found. These correspond in a general way with lines photographed by Dr. Schuster with the slit spectroscope in 1886. Many other lines have been photographed in the corona, but while some of these are probably genuine, others are undoubtedly due to atmospheric glare. On account of the uncertainty regarding the wave-lengths of the corona lines, Professor Lockyer has not hitherto been able to determine whether they are represented by dark lines in the solar spectrum. He remarks, however, that if present at all, they are among the feeble lines.

Some stress is laid on the apparent absence of the 1474 ring from the spectra of the chromosphere and prominences. Professor Lockyer concludes that when 1474 is seen at the Sun's limb without an eclipse, the spectrum of the corona itself is really observed and not that of the chromosphere. In support of this he states that he is not aware of any observation of the *form* of the prominences in 1474 light. It is true that such observations are very uncommon, but a case of this kind has been described by Fenyi[1] in a brilliant eruptive prominence observed in the vicinity of the great spot-group of February 1892, when it was at the limb. The form of the base could be distinctly seen in the 1474 line up to a height of 33″. Again, 1474 appears in the solar spectrum as a dark line, and there seems to be no good

[1] *A. and A.*, **11**, 432, 1892.

reason to suppose that it does not belong to the spectrum of the chromosphere, where it is always visible.

At this eclipse, as at all others where the prismatic camera has been used, H and K were not recorded as rings in the coronal spectrum. They have frequently been photographed across the corona with slit spectroscopes, but it is now generally believed that this was due to scattering of the light of the chromosphere and prominences in our own atmosphere. It can now in all probability be considered as definitely established that the H and K lines do not properly belong to the coronal spectrum. Dr. Schuster reached this same conclusion in 1886.

As has already been remarked, the photographs show a strong continuous spectrum due to the corona. Professor Lockyer is inclined to consider that this is not truly a continuous spectrum, but rather one filled with maxima and minima of brightness, producing a ribbed appearance. This conclusion is, of course, not based upon the results obtained with the prismatic camera, but rather upon a hasty observation of his own in 1882. Until this observation has been confirmed the spectrum will probably be considered to be continuous.

In his discussion of the variability of the spectrum of the corona, it cannot be said that Professor Lockyer reaches any very certain conclusions. In 1871 the 1474 ring appeared to him very bright, but in 1878 he did not see it at all. It was, however, seen as a faint line by Professor Eastman. It was also seen in 1882, 1883 and 1893 near times of Sun-spot maxima, and in 1889 by Professor Keeler near a minimum. While the observations seem to show that its brilliancy was rather less at eclipses which occurred near the Sun-spot minimum, it can hardly be said that a periodic variation in brightness can be considered as established, especially when it is remembered that the 1474 ring photographed in 1896 was quite as strong as that photographed in 1893.

Experiments made by Mr. Fowler with the prismatic camera have shown that under certain conditions false rings can be both seen and photographed. These results have thrown some doubt upon the origin of rings which have been ascribed to hydrogen, though it would appear that in one or two eclipses hydrogen was probably present in the inner corona.

The wave-length tables which conclude the memoir contain about 250 lines. All lines seen on any of the negatives are recorded, whether

they belong to the spectrum of the chromosphere or prominences. Many of these lines have previously been observed in full sunlight or at previous eclipses, but a large number are new. The intensities are recorded on a scale of 10, the strongest line in each negative, irrespective of exposure, being given this maximum value. The great majority of lines are shown to increase in intensity as they approach the photosphere, but great stress is laid on the fact that a few lines seem to gain in brightness in passing out from the limb. It should be remarked, however, that results of this character, which are directly opposed to those ordinarily obtained in daily observations of the spectrum of the chromosphere and prominences, should be received with great caution. It is of course well known that prominences are not infrequently brighter at the top than at the bottom, so that the lines in their spectra have their maximum brightness at some distance from the Sun's limb. But this depends upon local peculiarities of structure, and can hardly be considered to have any relation to hypothetical "layers" in the solar atmosphere. In general, lines in the spectrum of prominences are brightest near the base, and brighter still in the chromosphere. Professor Lockyer bases his conclusion that the "prominences must be fed from the outer parts of the solar atmosphere" in part on the fact that the spectrum of a very bright metallic prominence shows lines which are absent from the spectrum of the chromosphere, not immediately beneath the prominence, but some distance away. The reason given for making such a comparison is that "it is fair to consider the base of the chromosphere homogeneous" (p. 607). Those who have been accustomed to observe the spectrum of the Sun's limb below eruptive prominences will not be likely to agree in this opinion.

The results obtained by Mr. Shackleton at the 1896 eclipse render unnecessary a discussion of the bearing of the 1893 results on the question of the "reversing layer." The photograph of the "flash" spectrum, which has been exhibited by Professor Lockyer to the Royal Society, will soon be reproduced in this JOURNAL. It is stated by a well-known writer in the London *Times* that there can no longer be any doubt regarding the existence of the stratum whose spectrum was first observed by Professor Young in 1870. G. E. H.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

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NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, with be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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PLATE XI.

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME V APRIL 1897 NUMBER 4

SPECTROSCOPIC NOTES.

By W. W. Campbell.

THE HARVARD STAR, Z CENTAURI.

In December 1895, the *H. C. O. Circular* No. 4 announced that a "new star" had just been discovered by Mrs. Fleming, from an examination of the Draper Memorial photographs taken at Arequipa, Peru. The *Circular* stated that the star was situated very near the nebula *N. G. C.* 5253; that no trace of the star could be found on 55 plates taken from 1889 May 21 to 1895 June 14; that its magnitude on 1895 July 8 and July 10 was 7.2, and on 1895 December 19 was about 11; that an examination with a prism on December 19 showed that the spectrum was monochromatic, and closely resembled that of the adjacent nebula; and that, like the new stars in Cygnus, Auriga and Norma, this star appeared to have changed into a gaseous nebula.

The star was at once observed at Mt. Hamilton. It was found to follow the nucleus of *N. G. C.* 5253 by $1^s.4$ and was north of it 18″. Its position for 1875.0 was[1]

$$\alpha = 13^h\ 32^m\ 51^s.9, \quad \delta = -30°\ 59'\ 58''.$$

On the nights of 1895 December 22 and 29 I examined the

[1] *Ast. Jour.*, 16, 85.

spectrum of the star—then 11.2 magnitude—and was reasonably certain the spectrum was continuous, but the seeing was too poor to permit a definite decision. It was certainly not nebular. On the morning of February 8, 1896, the conditions were good, and I carefully examined the spectra of the star and the adjacent nebula, using the large spectroscope and 60° crown prism. The nebula's spectrum was of the usual type, the lines at λλ 5007, 4959 and 4862 having their usual relative intensities. The line near λ 4690 seemed to be present, as in the case of *N. G. C.* 7027 and *G. C.* 4964. The spectrum of the Harvard star was *continuous*, though very peculiar. The maximum visual intensity was in the yellow-green, the green-blue was very faint, while the blue was surprisingly strong. In fact, the blue was very much brighter visually than the green-blue. The spectrum was relatively very faint from about λ 5200 to λ 4600. There was no trace of the nebular lines visible, nor of the $H\beta$ line. There was some evidence of bright lines or of irregularities in the brightest portions of the spectrum, but the light was too weak to enable me to decide. The slit was at right-angles to the line joining the star and the nebula. By pressing against the telescope the two spectra were alternately brought into view. The nebular spectrum thus formed a good basis of comparison, and the star spectrum in no wise resembled it.

The Harvard observation of the spectrum was made on December 19 with the 15-inch telescope, when the star was of the 11th magnitude, very low in the sky and near the Sun. The continuous spectrum under such circumstances would be exceedingly faint. The star and nebula are less than 30″ apart. Is it not possible that the observed spectrum was that of the nebula, and not that of the star?

On June 11, 1896, Professor Hussey observed that the star had decreased in brightness to 14.4 magnitude, and that it was surrounded by a faint, irregular nebula which seemed to extend continuously to the main nebula south preceding. On July 9 he observed the star to be of the 16th magnitude, and the nebulosity surrounding it was plainly seen to be continuous with the

bright adjacent nebula, *N. G. C.* 5253. That the nebulous background was not seen earlier was probably due to the overpowering light of the star. On January 4, 1897, Professor Hussey looked for the star, without success: it was fainter than 16¼ magnitude, and invisible.

Some writers have contended that this star is not a "new star," but that it is identical with *Cord. DM.* -31° 10536,[1] observed on four nights in 1885–92 at Cordoba. While I do not want to enter upon a discussion of this question—at present unsolved and not now capable of solution, apparently—I may perhaps express my opinion that all the evidence available points to the identity of the nebula *N. G. C.* 5253 and the star *Cord. DM.* -31°10536. The evidence that the Harvard star was observed previous to 1895 July 8 is confined to the single Cordoba date, 1887 April 12.

If the star is simply a variable, as some writers contend, its period must be very long, or its variations very irregular.

If the star is to be classed with the "temporary" stars, it is not analogous to the new stars in Cygnus, Auriga and Norma, but rather to the star of 1885 in the Andromeda Nebula.

THE SPECTRUM OF MARS.

My visual spectroscopic observations of Mars and the Moon in 1894, under extremely favorable circumstances, led me to conclude that the two spectra were apparently identical, so far as visual estimates of the intensities of the telluric lines were concerned. My paper on the subject stated the conclusions to be drawn from the observations as plainly as it would be possible even now to state them. Nevertheless, they were misunderstood persistently by many reviewers, and I beg to re-state them here, viz.:

While the polar caps are conclusive evidence of the presence of atmosphere and vapor (probably water-vapor) on Mars, yet these do not seem to exist in sufficient quantities to have been detected by any spectroscopic observations thus far made; and

[1] *Ast. Jour.* **16**, 16, 106, 165, 166.

my observations indicate that the density of the atmosphere at the surface of Mars is not more than half as great as the density of our atmosphere at the summit of the Himalaya Mountains.

Thus far, all the observations were visual, though there were plates sensitive to the light from the region of the important δ vapor band. In March 1895 I obtained a few photographs of the spectra of Mars and the Moon, on Cramer's isochromatic plates, using the large Brashear spectroscope and a 60° crown prism. The photographs covered the region of the δ band. There was no visible difference in the spectra of the two objects, though the conditions were not first-class.

On October 22, 1895, using the apparatus described above, I obtained a long series of photographs of both spectra. The dew-point for the night was 0° Centigrade. Some of the negatives were copied on lantern-slide plates, for the purpose of increasing the contrasts in the spectra. Neither the original negatives, nor the positives on slow plates, revealed any differences in the two spectra. However, a comparison of the plates corresponding to high and low altitudes, convinced me that the photographic method *with low dispersion* is not so sensitive as the visual method with the same dispersion. On December 18, 1896, I obtained a few photographs, using a fourth-order grating. It was necessary to use a rather wide slit, and the negatives were considerably underexposed, though comparable in the δ region. There was no visible difference in the spectra, but the result is purely negative, for two reasons: (*a*) The negatives are not as dense as they should be; and (*b*) I was unable to secure photographs at low altitudes, to test the sensitiveness of the method. I believe the photographic method with high dispersion is fully as sensitive as the visual method with low dispersion; but to what extent it is more sensitive I cannot say. A train of three flint prisms would have been much more efficient than the grating, but such a train was not available.

There has been some discussion as to whether high or low dispersion should be used in such a problem as this. Not to enter upon a consideration of the general question, I may per-

haps make one or two remarks. In the photographic study of a spectrum, such as that of Mars, the question of brightness does not enter, except as it affects the exposure time. When the visual method is used, the question of brightness does enter. It is then a question of getting *a little something* with low dispersion, or *nothing at all* with high dispersion. It has been my experience that those who have not observed spectra at night invariably overestimate the brightness of those spectra.

COMET 1895 IV (PERRINE).

Visual observations on November 17, 1895, showed the yellow, green and blue bands of carbon, with their usual relative intensities, together with a strong continuous spectrum.

A photograph taken December 8, 1895, showed the following features:

The blue carbon band, unresolved, maximum near λ 4690.

λ 4366 bright line, easy.

λ 4313 " " faint.

λ 4298 " "

λ 4214 " " very easy, cyanogen.

λ 4196 " " easy, cyanogen.

Traces of several bright lines between $\lambda\lambda$ 4100–4000 (cyanogen ?).

λ 3881 brightest line on plate, cyanogen.

λ 3870 very bright line, cyanogen.

Continuous spectrum between $\lambda\lambda$ 4700–4000, which has a fluted appearance, as if caused by the principal groups of absorption lines in the solar spectrum, notably the group at G.

COMET 1895 V (BROOKS).

On November 22, 1895, visual observations showed that the spectrum was of the usual character. The spectrum was too faint to photograph.

COMET 1896 I (PERRINE).

On February 19, 1896, the visual spectrum was of the usual character. A photograph recorded the bright cyanogen lines

at $\lambda\lambda$ 3881 and 3870. No other lines were recorded, on account of the faintness of the comet, which was not visible to the naked eye.

COMET 1896 III (SWIFT).

On April 30, 1896, the visual spectrum was of the usual character. The spectrum was too faint to photograph.

COMET 1889–96 (BROOKS-JAVELLE).

Visual observations were made on August 15, and October 6, 1896. The comet was about 13th magnitude. The continuous spectrum was plainly visible, and I was pretty certain that a trace of the green carbon band was visible, but not absolutely certain. There was no doubt that the continuous spectrum was relatively much stronger than the gaseous carbon bands in this comet, than in any of the other comets I have observed, except in the case of Holmes' comet of 1892.

These comet photographs and many of the visual observations, were made with the 12-inch telescope and the large Brashear spectroscope mounted in a wooden case, using a 60° crown prism. This combination is very effective for photographing comet spectra, except that the clock and slow motions are unsatisfactory, and render the guiding very difficult. Further, this combination permitted me to make the observations without interfering with the regular spectroscopic work in the large dome. An extensive and expensive equipment is not necessary for the study of comet spectra, and the subject is seriously neglected. I desire especially to call attention to the importance of observing the spectra of periodic comets, both visually and photographically, at every opportunity. It is a good working hypothesis that the continuous spectrum is relatively stronger in periodic comets than in parabolic ones. As a comet approaches the Sun, its more volatile constituents are excited, electrically or otherwise, and are probably driven off permanently from the mass of the comet. For a parabolic comet this effect would be temporary, while for a periodic comet it would go on constantly, under

the Sun's influence; in which case it would seem that the bright-line spectrum of a periodic comet should gradually become less prominent. This view is supported by the observed spectra of Comet III, 1892 (Holmes) and Comet 1889–96 (Brooks-Javelle), and possibly by the meagerness of carbon in meteorites.

The four comet spectra which I have thus far been able to photograph, viz.,

1893 II (Rordame),
1894 II (Gale),
1895 IV (Perrine),
1896 I (Perrine),

have been identical so far as the different intensities of the four permitted comparison. All were parabolic comets.

NOVA AURIGÆ.

Occasional observations for the magnitude of the new star of 1892 in Auriga have been made. No change in brightness has been recorded since 1892.

In Vol. I., No. 1, of this JOURNAL I called attention to the remarkable changes going on in this star's spectrum. It was shown that the bright lines $\lambda 4360$ and $\lambda 5750$ which were very bright in August 1892 had become very faint in 1894. No photographs have been secured since November 1894, but visual observations show that the change in the line $\lambda 5750$ has been progressive. The observed intensities of six of the principal bright lines have been as follows:

	$H\gamma$	$\lambda 4360$	$H\beta$	$\lambda 4960$	$\lambda 5010$	$\lambda 5750$
1892 August and September......	0.1	0.8	1	3	10	1
1894 May 8	0.1	0.3	1	3	10	0.4
1894 September 7...............	0.1	0.2	1	3	10	0.4
1894 November 28	0.1	0.1	1	3	10	0.3
1896 August 15..................	—	—	1	3	10	0.1
1896 October 6.................	—	—	1	3	10	0.1

At the date of the last observation the line $\lambda 5750$ was difficult to see at all.

It is especially significant that the lines λ4360 and λ5750 should be the ones to change. The first measures of the spectrum in August 1892 showed unmistakably that it was the spectrum of a nebula. At first, however, the lines λ4360 and λ5750 did not seem to exist in the old nebulæ. But photographs of their spectra at once showed the line λ4360 in five well-known nebulæ, and visual observations showed the line λ5750 in three nebulæ. These lines were strong in the *Nova*, but relatively faint in the old nebulæ. They have now become relatively faint, in fact practically invisible, in the *Nova*. The spectrum of the new star has lost its anomalies: it is now of the ordinary type of nebular spectrum, save that the lines remain broad, as they have always been described.

As my apparatus has been arranged, it has not been convenient to re-measure the wave-lengths of the principal nebular lines since November 1894. The last few measures secured were made with a dense 60° flint prism and magnifying power 26—a combination much preferable to the grating and low power employed in the earlier measures.

While the spectroscopic observations of *Nova Aurigæ* show it to be *truly nebular*, there has been a question as to whether the nebulosity is *actually visible* in the focal image of a telescope.

When the reappearance of the *Nova* was observed on August 17, 1892 by Messrs. Holden, Schæberle and Campbell, "all the observers agreed that its appearance was different from that of other stars of the same magnitude."[1] Later Professor Barnard announced[2] that the object was "really a small bright nebula with a 10th magnitude nucleus. . . . . With the micrometer the nebulosity was found to be 3″ in diameter—a fainter nebulosity still surrounded this and was perhaps ½′ in diameter."

Mr. Newall suggested[3] that the nebulous appearance was not real, but was due to the chromatic aberration of the object-glass, and that the image was truly stellar. This suggestion was

[1] *A. and A.*, 11, 715.

[2] *A. and A.*, 11, 751.

[3] *Nature*, 46, 189.

repeated and carefully elaborated by Professor Vogel.[1] Dr. Huggins,[2] observing with a reflecting telescope, which is free from chromatic aberration, saw the image as a stellar point.

The focal image of the *Nova* in the 36-inch telescope certainly looked substantially as Professor Barnard described it.[3] But further consideration of the problem, together with actual experiments on the *Nova* and on the Wolf-Rayet star $+30° 3639$,[4] soon convinced me that the 36-inch telescope, with its strong chromatic aberration, was not suitable for deciding this question definitely. For if any one of the numerous monochromatic images were brought into focus, all the others would be out of focus, and would combine to form a halo surrounding the central image. The yellow image at $\lambda 5750$, so long as it remained bright, augmented the difficulty.

I therefore determined to estimate the diameter of the *Nova* by observing the width of its spectrum. Observations for that purpose were made in the fall of 1893 and of 1894. The rather coarse micrometer wire was placed lengthwise of the spectrum, and its width was such as just to occult the principal nebular line when the atmospheric conditions were fair. From the known width of the wire and the proportions of the spectroscope and telescope, the angular width of the wire was computed to be $1\frac{1}{2}$ seconds of arc. On none of the nights utilized was the seeing perfect; but I attempted to eliminate the effect of imperfect seeing by observing, in the same manner, the continuous spectrum of a star so selected that its spectrum at $\lambda 5010$ and the principal nebular line would be of about equal intensities. In every case the two spectra were practically of the same width, thereby indicating that *the focal image of Nova Aurigæ is stellar.* At the same time it must not be forgotten that *Nova Aurigæ* is a true nebula: the spectroscopic evidence is indisputable.

[1] *Über den neuen Stern im Fuhrmann*, Berlin, 1893.

[2] *A. and A.*, **13**, 314-315.

[3] *A. and A.*, **12**, 419.

[4] This star has a hydrogen atmosphere, 5″ in diameter. *A. and A.*, **13**, 461.

The publication of these observations of the *Nova* has been unduly delayed — at first from a desire to repeat them on a first-class night, and later by the hope that the 36-inch Crossley reflector would be available for repeating them. As soon as the reflector is available I shall endeavor to get its testimony on this interesting question.

LICK OBSERVATORY,
UNIVERSITY OF CALIFORNIA,
March 3, 1897.

ON THE SPECTRUM OF HYDROGEN.

By H. KAYSER.

In the Harvard College Observatory *Circular* No. 16 I see that Professor Pickering has come to the conclusion that the lines he discovered in the spectrum of ζ Puppis belong to hydrogen, because he is able to represent the old hydrogen series and the new lines by one formula as a single series. This possibility shows better than anything else could do the correctness of my former statement, that the old hydrogen series and the new one end at nearly the same point. But I am sure that the representation of the two series as a single one is incorrect. My arguments are the following:

1. The analogy with all the other elements, which have two series ending at the same point in the spectrum.

2. The different appearance of the lines of the two series; in every true series the lines have the same character, and become fainter as the shorter wave-lengths are approached.

3. The different conditions of appearance; this difference is so great, that we are hitherto unable to produce the second series.

4. For all the elements the second constant in our formula $\frac{1}{\lambda} = A - Bn^{-2} - Cn^{-4}$ has nearly the same value, so nearly indeed, that Rydberg believed the value to be exactly the same. But if we unite the two hydrogen series, then this constant has for hydrogen a value four times greater than for any of the other elements.

All these arguments seem to show conclusively that we must assume two series in the spectrum of hydrogen; it then corresponds admirably with the other elements.

BONN, February 2, 1897.

THE CAUSE OF THE DARKNESS OF SUN-SPOTS.

By J. Evershed.

The most generally received doctrine as to the constitution of the Sun is probably that in which the entire internal mass of that body is regarded as being in a gaseous condition; the temperature, below the photospheric layer, being above the critical point of all known substances. The low mean density is accounted for by supposing that the temperature increases rapidly with the depth below the surface, the expansive energy of the internal gaseous nucleus largely counteracting the enormous force of compression due to gravity.

It appears to be pretty generally admitted, too, by recent writers, that the photosphere is a surface of condensation; a region, exposed to the cold of space, where elements of high boiling point, such as those of the carbon group, are precipitating from the gaseous state and forming clouds of highly emissive solid or liquid particles.

I propose in this paper to discuss the question as to the cause of the relative darkness of Sun-spots on the basis of these fundamental ideas, and with special reference to the recent work of W. E. Wilson on the "Thermal Radiation of Sun-spots."

Most spot theories in vogue at the present time attribute the blackness of spots to masses of relatively cool vaporous material which absorbs the intense light of the underlying photosphere. Thus in Secchi's theory a spot is regarded as a kind of sink in the photosphere, into which the materials which have been erupted in the neighborhood are settling down again into the body of the Sun, forming a great cloud of cool absorbing vapors. Faye believes spots to be vortices set up by the relative drift of adjacent portions of the photosphere, the dark absorbing material accumulating in the vortex by reason of the indraught. Oppolzer likens a spot to a disturbed region in our atmosphere in which great contrasts of temperature arise; and he explains the

obscurity in the same way as a result of increased absorption by relatively cool vapors.

Many other theories have been proposed in which absorption is regarded as the principal factor in causing the darkness, and the evidence afforded by the spectroscope seems always to have been taken as practically demonstrating the truth of this hypothesis.

But absorption as ordinarily understood is in many respects very difficult to reconcile with the common features of spot formation. The well-defined structure and abrupt transitions in passing from photosphere to penumbra, and from penumbra to umbra, points rather to the *absence* of the bright photospheric clouds from the spot, than to their suppression beneath a mass of absorbing material; and seems much more suggestive of an actual rent in the photospheric layer through which a less luminous region is revealed.

Quite recently in a paper on the "Level of Sun-spots,"[1] read before the British Astronomical Association, Mr. Maunder argues that absorption can have but little effect in causing the spot darkness, for whether the spot be regarded as a depression or an elevation compared with the photosphere, the obscuring effect of an absorbing layer would be vastly increased when near the Sun's limb as compared with its effect at the center of the disk, owing to the foreshortening; and the greater the area of the spot the more noticeable would this become, so that in many cases the entire spot would appear as black as the umbra when near the limb. As this is not the case at all, the conclusion is drawn that diminished radiation rather than increased absorption is mainly operative in a spot.

In the same paper Mr. Maunder suggests that a spot may be regarded as a region of high temperature in which the condensation of highly incandescent carbon does not take place to the same extent as in the photosphere, the diminished radiation being due to the relatively low emissive power of the gaseous contents of the spot; just as in an ordinary gas burner the pre-

[1] *Jour. B. A. A.*, 7, No. 3.

cipitation of solid carbon produces a bright luminosity, whilst the purely gaseous portion of the flame glows but feebly.

This explanation of spot darkness certainly harmonizes very well with the observed structure of spots and with many of the attendant phenomena, such as the great brilliancy of the faculous bridges and the surrounding faculous region; the intensification of the H and K lines and frequently of the hydrogen lines over the entire spot region; all of which suggest that a spot is really a center of relatively high temperature.

Unfortunately it is open to a very serious objection when we consider the application of Kirchhoff's law to solar conditions. For suppose we liken a spot to a non-luminous Bunsen flame, or better, to a pure hydrogen flame burning in air, and a bright facula bridging the spot to a platinum wire held in the flame. The analogy would at first sight appear to be a very striking one, the hydrogen flame emitting a very feeble continuous spectrum and the glowing solid a very brilliant one, although no hotter than the flame. But yet according to Kirchhoff's law the feeble emissive power of the gas is exactly compensated by its feeble absorptive power, so that if we were to increase the thickness of the non-luminous flame indefinitely the brightness would increase, until finally, it would equal that of the glowing solid; even that of a theoretically "black" solid which has the highest emissive power. This condition would be reached when the radiating gas was of such thickness as to be entirely opaque to transmitted light.[1]

In the case of the Sun-spot, therefore, we should expect that the immense and practically unlimited depth of the interior gases would compensate for their relatively feeble radiating power, even if we took no account of the much higher temperature and high state of compression of the interior regions. There seems to be no escape from this difficulty, even if we imagine the interior of the Sun to be absolutely non-luminous, for then,

[1] The cumulative effect of a great thickness of radiating gas can easily be shown with a row of Bunsen flames such as are used in tube furnaces. If these are observed "end on" the brightness is seen to increase in proportion to the number of flames, or very nearly so.

according to Kirchhoff, it will also be absolutely transparent, and the photosphere on the opposite side would be seen through the spot opening.

Again, if the internal gases are so compressed as to be practically opaque like solids, then they must radiate like solids, they cannot continue to accumulate the energy acquired by absorption indefinitely. Thus we seem driven back again to some modification of the absorption hypothesis, unless we find that the ordinary laws of heat exchange are not applicable under solar conditions.

The structural characteristics of spots might perhaps be explained on the absorption hypothesis by supposing that the cooled absorbing material was situated at a considerable depth, being partly overlaid and encroached upon by the photosphere, the spot opening being at the same time filled up with dark material; and it would be natural to suppose this absorbing material to be the same as that which everywhere covers the Sun, producing the absorption at the limb, and giving rise to the mottled appearance of the disk due to variations in level of the photospheric clouds in this smoke-like veil. Thus there would be no real distinction to be drawn between a well-developed spot and the minute pores and interspaces between the photospheric clouds. It will be shown later, however, that there is a very marked difference in the character of the spot darkening and the general shading at the limb. It is clear that if a spot is really an accumulation of absorbing vapors it must be cooler than the photosphere, whilst if on the other hand, it is an opening where the photospheric clouds have been evaporated, we must regard it as being as hot as or hotter than the surrounding region. Evidence in support of the absorption hypothesis has been frequently derived from the widened lines seen in spot spectra, which are supposed to indicate a lower temperature in the absorbing gases. But the widening is at the most very slight; a proportionally slight increase in the depth of the gases concerned will equally well account for it. Furthermore, only a very small proportion of the lines in the spectrum are widened

or intensified; probably many others are weakened, or suppressed altogether even when they do not appear as *bright* lines. It has not, perhaps, been sufficiently realized that a large proportion of the light we are dealing with in the spectrum of a dark nucleus is not derived from the spot at all, but is simply photospheric light reflected from the sky; the contrast between the umbra and the sky illumination outside the limb being in many cases almost inappreciable. Thus the majority of the Fraunhofer lines in the umbral spectrum may be spurious lines; could we remove our atmosphere and wholly isolate the umbral light, it is quite possible that the spectrum would be found to be, in the main, an emission spectrum.

However this may be, the widened lines are evidently not a satisfactory criterion as to the relative temperature of spots and photosphere, and the slight extra amount of gaseous absorption implied by their presence can have practically no effect on the darkness of spots. This is obviously due to the general darkening, which is apparently continuous all along the visible spectrum, and may or may not be the result of absorption. The resolution of a portion of the spot band by Professor Young into innumerable closely crowded dark lines with occasional bright intervals,[1] would seem to point to absorption, but absorption by gaseous rather than solid or liquid matter.

In the opinion of the writer, no satisfactory explanation of spot darkness is likely to be arrived at until the spot band itself has received the closest investigation, both in the visible and invisible regions of the spectrum, particularly with regard to the relative intensity and character of the band and quite apart from the question of widened lines or bright lines, which can only give information as to the condition of the gases in the overlying reversing layer and chromosphere, and which taken all together can have but little influence on the general radiation of the spot.

THE THERMAL VALUE OF THE SPOT RADIATION.

The measurements of total radiation from spots by Langley,

[1] Young, *The Sun*, 4th ed., p. 323.

using a bolometer, and recently by W. E. Wilson with a radio-micrometer, do not give any direct information as to the relative temperatures of photosphere and spots; the relative emissive powers being unknown. Indirectly, however, they would seem to afford a clew.

In the thermal measuring apparatus the blackened receiving surface may be supposed to absorb indiscriminately all the radiant energy falling upon it, whatever the wave-length, that is, the whole range of wave-lengths, including of course the visible rays. Thus the measurements sum up the energy in the entire spectrum, and show, as it were, the *average* darkness of the spot band when the whole spectrum is taken into account.

The results show that a spot is very much less dark measured thermally than visually. The spot band is, therefore, much darker in the visible region of the spectrum than it is in other regions; where, it would seem, it may even be *reversed*. This fact is the more striking, when we consider that in ordinary sunlight the rays which possess the maximum heating power are those about the middle of the visible spectrum, so that one would expect, *a priori*, to find a practical agreement between thermal and photometric estimates of the darkness.

Referring to Mr. Wilson's paper (*Monthly Notices*, Vol. LV, No. 8), the monthly mean values of the umbral radiation are found to vary from .35 to over .50; that of the photosphere at the center of the disk being 1.00. The photosphere radiation, however, rapidly diminishes from the center towards the limb where it becomes .45, whilst the spot radiation remains nearly constant in all positions on the disk. Thus the ratio between the radiation of the spot and that of the *neighboring* photosphere approaches unity as the spot nears the limb. The highest value of this ratio recorded by Mr. Wilson is .83, but both Langley and Frost have measured spots in which the thermal intensity even exceeded that of the surrounding photosphere.

With regard to the visible radiation of spots, it is quite obvious from ordinary telescopic observation that the umbra of a normal spot does not emit more than a very small fraction of

the light of the photosphere, even of the neighboring photosphere, when the spot is near the limb. To make sure of this point the writer has roughly estimated the relative darkness of a spot by means of an Abney photometer, so arranged as to reduce the light of any portion of the photosphere by any known amount The results obtained show that the *penumbra* of an ordinary spot is not more than one-third or one-fourth as bright as the photosphere; whilst the umbra itself is probably in most cases less than one-twentieth.

The apparatus being incapable of measuring small fractions, this latter value is probably an upper limit, the intensity may have any value less than that; many spots must indeed be at least a hundred times less bright than the neighboring photosphere at the limb, for in this position the dark umbra often presents the illusion of a piece cut out of the limb; proving that no more light comes from the spot than from the sky outside. Perhaps the average spot nucleus is not however quite so dark as this, for during partial solar eclipses spots are said to appear lighter in tint than the black disk of the Moon.

But whatever may be the true photometric value of the spot darkness the discrepancy between thermal and visual estimates is evidently very marked, and it would be of great interest to determine in what region of the spot spectrum the extra energy is to be found, which is shown by the relatively high thermal value of the radiation. Does the spot band become less dark or even reversed, in the infra-red or in the ultra-violet?

The question of the relative temperature of spots and photosphere must largely depend on the position in the spectrum of this region of maximum intensity. For suppose we admit that the whole of the Sun's interior below the photosphere behaves like an opaque solid as regards radiation. The emission spectrum will be a continuous one; but the distribution of energy in the spectrum will not be uniform. The wave-length of the rays of greatest intensity will depend on the temperature, the wave-length decreasing with increase of temperature according to a well-established law of radiating solids. Now the temperature

of the photosphere is such as to give, according to Langley, a maximum in the visible spectrum. But deep down in the interior the temperature must be enormously higher and the wave-length of maximum energy from that region must be shifted far into the ultra-violet.

If then in a spot we have a glimpse of the interior intensely hot regions below the photosphere we should expect to find the spot spectrum brighter (or less dark) in the ultra-violet. But if relatively cool absorbing vapors are the principal cause of spot darkness, then the maximum should be found in the infra-red; not a true emission maximum perhaps, but a part of the spectrum where the absorption has less influence than in the visible spectrum.

There is one point which would seem to be definitely settled by the thermal measures. It has been previously mentioned that the spot darkness and the general shading at the limb are different in character. This results from a comparison between the thermal and visual estimates of the darkening in the two cases. In the limb absorption the discordance between these measures is not greater than would be the case assuming it is due to a smoke-like layer which absorbs the blue rays more completely than the red and yellow, which in sunlight have the greater heating power, a feature too that is well brought out by Vogel's detailed measures made in different colors. But the spot darkness is evidently of a different character, the thermal intensity being extraordinarily high, and it is certainly not possible to explain it by assuming a greater thickness of the *same* absorbing material.

For supposing we reject Langley's and Frost's measures of abnormal spots giving a higher thermal intensity than the photosphere and consider Wilson's average result, namely .75 at .95 from the Sun's center, to be an overestimate. If a spot near the limb gave only .66 of the thermal effect of the surrounding photosphere, then, assuming the darkening of spot and limb to be only a question of degree, this would imply in the spot a 34 per cent. absorbing layer added to that which gives the general

absorption. But a layer which absorbs 34 per cent. of general radiation (heat) will absorb 46 per cent of light[1] if it is of the same material which covers the photosphere, leaving .54 as the photometric value of the umbra compared with the adjacent photosphere, or about .25 compared with the center of the disk; values which are evidently quite inadmissible, for large spots near the limb often appear as dark as the sky, their intrinsic light being only a minute fraction of that of the surrounding region.

A possible clue as to spot darkness has occurred to the writer which does not necessitate absorption and still does not violate the ordinary laws of heat exchange. The temperature gradient in the Sun is not known, but it is believed that the temperature near the surface must increase very rapidly with the depth. According to Oppolzer this increase must be at least 6000° C. for each second of arc (see *Astronomy and Astrophysics*, Oct. 1893, p. 736). A few thousand miles below the photosphere therefore the temperature must enormously transcend that of the Sun's visible surface. Is it possible that the radiation from this inconceivably hot interior region takes place in wave frequencies of a higher order altogether than that of the photosphere?— the visible radiations being relatively feeble.

This assumes that in a radiating body at high temperature the intensity of the longest waves tends to diminish with increase of temperature. That is, as the radiations of maximum energy move up the spectrum with increasing temperature, the actual as well as relative intensity in the lower region of the spectrum must be supposed to diminish.

In a general way the shifting of the maximum intensity towards the violet with increase of temperature may be said to be confirmed by star spectra. It is well known that the photographic magnitudes of many stars do not correspond with the visual magnitudes. Thus the first type stars are photographi-

[1] Compare the tables of absorption given by Wilson and Rambaut: "The Absorption of Heat in the Solar Atmosphere" (*Proc. Royal Irish Acad.*, 3d series, Vol. II, No. 2), and Young, *The Sun*, 4th ed. p. 247.

cally brighter than solar stars of the same visual magnitude, that is the blue and violet in the spectrum of the hotter stars is relatively brighter than the yellow and red.

Whether the red rays are really less bright in the Sirian stars than would be the case if the temperature were reduced to that of the solar stars, it is not possible to say. Langley has found however, that very far down in the normal solar spectrum the intensity is very much less than might have been expected. He found it easier, in fact, to detect these long waves in the spectrum emitted by a copper vessel filled with boiling water, and even in the rays of the Moon when its surface has become slightly warmed by the Sun.[1]

It would seem not impossible therefore that in the radiation of a Sun-spot this relatively feeble part of the spectrum has crept up into the shorter visible wave-lengths, following the rays of greatest energy which have traveled far up into the ultra-violet. It is true that if this be the real explanation of spot darkness the total radiation of the umbra should greatly exceed that of the photosphere, whereas according to Wilson's measures it is never even equal to it. It is probable, however, that the bulk of the energy would be absorbed by the Earth's atmosphere, which is a far more efficient screen for the ultra-violet rays than for visible light. It would seem too, that some of the energy does not assume the form of heat on reaching the Earth, but is effective in producing those magnetic disturbances which are characteristic of large umbræ.

But as the writer has already pointed out, a little further research into the character of the spot band in the invisible reaches of the spectrum would doubtless throw much light on the question, even if it did not at once demolish the above somewhat speculative theory.

[1] S. P. Langley, "The Solar and Lunar Spectrum" *Mem. Nat. Acad Sci.*, Vol. IV. Part. I.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

II. THE BUILDING AND MINOR INSTRUMENTS.

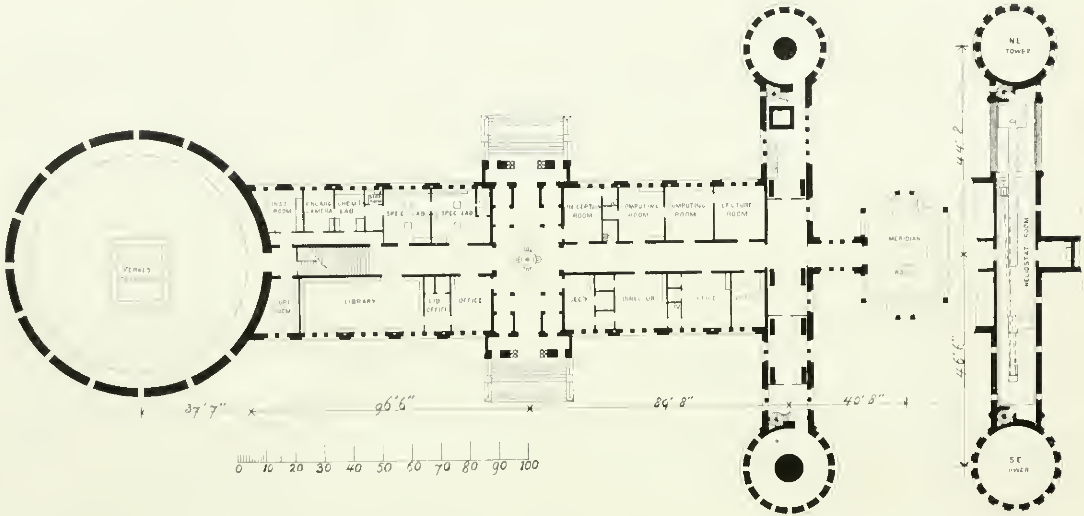
By George E. Hale.

Reference has already been made to the plan of work prepared for the Yerkes Observatory in 1892.[1] This choice of subjects for investigation followed naturally and simply from a consideration of the special advantages of the forty-inch telescope, the principal instrument of the Observatory. These advantages are: (1) high resolving power, adapting it for observations of double stars, and minute detail in the surface markings of the Sun, Moon, planets, and satellites; (2) great light-gathering power, making possible spectroscopic studies of faint stars, and micrometric and photometric observations of faint satellites, stars, and nebulæ, variable stars at times of minimum brightness, and comets long after perihelion passage; (3) great focal length, giving large images in the principal focal plane of the Sun, planets, and planetary nebulæ, admirably suited for spectroscopic work. It was decided that in order to derive the greatest possible return from the use of the great telescope, full provision should be made for carrying on investigations in these various fields of work. The greater part of these observations being of an astrophysical character, it became necessary to provide the Observatory with laboratories equipped for the numerous researches of a physical nature required for their interpretation.

There was another reason, no less important than those already mentioned, for emphasizing the astrophysical side of the Observatory's work. Although important astrophysical observatories existed at that time in France and Germany, and provision had been made for astrophysical work in the national observatories of England and Russia, there was no observatory in North

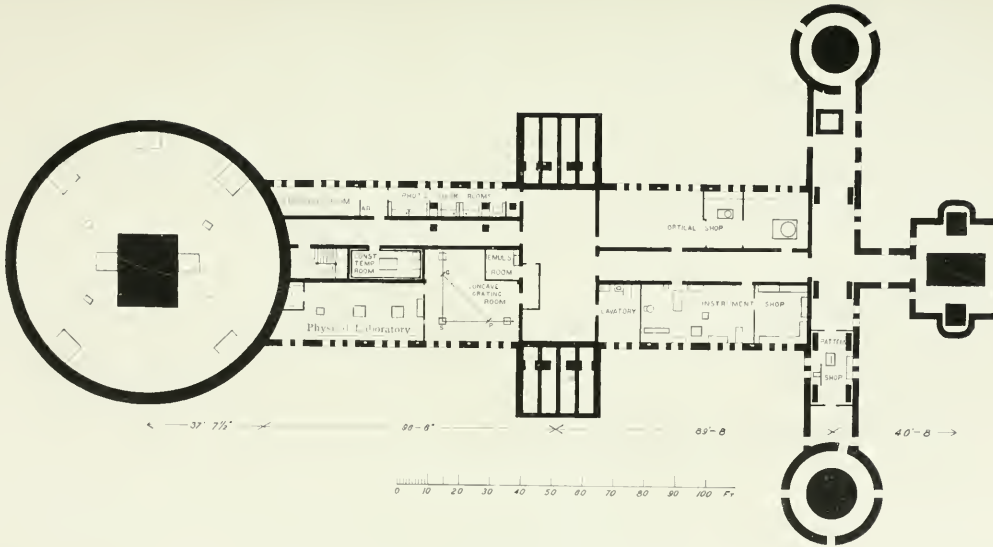
[1] See a previous article in this series, *Ap. J.* 5, 164, March 1897.

PLATE IX



MAIN FLOOR OF THE YERKES OBSERVATORY

PLATE X.



GROUND FLOOR OF THE YERKES OBSERVATORY.

America which was completely equipped for such investigations. The Allegheny Observatory probably represented more nearly than any other such a union of astronomy and physics as an astrophysical observatory implies; but in the absence of a large equipment and staff, the successive Directors, Professors Langley and Keeler, had necessarily confined their very successful work to investigations which could be carried on without the aid of large instruments. At the Harvard and Lick Observatories, where so many important researches had been made on the astronomical side of the subject, laboratories provided with the means necessary for attacking the more distinctly physical problems involved were lacking. On the other hand, such spectroscopic laboratories as that of Johns Hopkins University were unable, for lack of instrumental means, to carry their fundamentally important researches beyond the artificial boundaries of physics into the realm of astronomy. At the Smithsonian Institution Professor Langley had mounted in temporary quarters the apparatus used in his important bolometric researches, but Congress had not seen fit to provide funds for establishing on a proper scale a national astrophysical observatory.[1] In short, in spite of the wealth of observatories and laboratories in the United States, and the numerous contributions to astrophysics of Rutherford, Draper, Young, Pickering, Langley, Rowland, Keeler, Michelson, Hastings, and many others, there was yet to be founded an observatory which should adequately represent both the astronomical and physical sides of astrophysical work, at the same time providing the necessary facilities for research work in astronomy of position. It was therefore felt that an attempt should be made to meet this need, as adequately as circumstances would permit.

For instrumental equipment there was in the first place the forty-inch telescope, for which Mr. Yerkes had ordered a filar micrometer from Warner & Swasey, and a stellar spectrograph from Brashear; and in addition to this the instruments of the

[1] It is greatly to be hoped that Professor Langley's plans for creating such an observatory will soon be realized.

Kenwood Observatory, consisting of a twelve-inch refractor, fitted with both visual and photographic objectives, a spectroheliograph, and other attachments; a four-inch concave grating of ten feet focus, with complete mounting; and a collection of minor apparatus, including clocks, spectroscopes, gratings, prisms, etc. It was decided that there should be added as soon as possible a sixteen-inch refractor for micrometric work; a large heliostat with various accessory apparatus; a transit instrument, and subsequently a meridian circle; a large spectroheliograph and a solar spectroscope for the forty-inch equatorial; and a collection of instruments for laboratory work, including special spectroscopes, refractometers or "wave-comparers," and bolometric apparatus.

An attempt was then made to design a building which should meet as many as possible of the conditions imposed by the observations to be made with these various instruments.

Work on the plans was not begun until nearly all of the important observatories and spectroscopic laboratories of the United States and Europe had been visited and studied. Ideas were freely borrowed from these institutions, particularly from the Lick Observatory and the Astrophysical Observatory at Potsdam. The preliminary plans were completed at Berlin in February 1894, and despatched to the University architect, Mr Henry Ives Cobb of Chicago, who followed out the details with great care and success, sacrificing none of the scientific requirements for architectural effect.[1] Full credit for the architectural design is due to Mr. Cobb, as the writer is responsible only for the general form of the building, and for the interior arrangement only so far as this is determined by the requirements of the Observatory's work. Owing to the fact that The University did not come into possession of the property at Lake Geneva until late in the autumn of 1894, the work of construction could not be undertaken before the following spring. The interven

[1] This may not prove to be the case in the meridian room, which had been planned as a light iron skeleton, with double sheet-iron walls and intervening air space. The addition of the terra-cotta cornice will not tend to improve the conditions required for the best work.

CENTRAL ROTUNDA OF THE YERKES OBSERVATORY.

ing time was spent in perfecting the plans, which were much improved as a result of further study and the adoption of important suggestions kindly offered by various men of science, to whom the thanks of the Observatory are due. They were finally completed in February 1895, and the first excavations for the building were made in April of the same year. The work of construction was carried on with various interruptions through the two succeeding years, and is now (March 1897) nearly completed. The Observatory has been occupied by the present members of the staff since October 1896.

As will be seen from an inspection of the plans (Plates IX and X) the form of the building is that of a Latin cross, with three towers and a meridian room at the extremities. This form suggested itself as one permitting the various domes to be well separated, at the same time providing sufficient space for the laboratories and other rooms between the towers. The long axis of the building lies on an east and west line, and is 326 feet in length. The large tower at the western extremity, which contains the forty-inch telescope, is ninety-two feet in diameter. This tower, together with the large telescope, dome and rising-floor, will be described in a subsequent paper. For the present attention will be confined to the other parts of the Observatory.

An examination of the accompanying illustrations will show that Mr. Cobb has worked out the design in the Romanesque style, with somewhat Saracenic details recalling the Church and Monastery of Monreale. The north and south entrances (Plate XI), which lead into the central rotunda (Plate XII), are in all respects precisely similar. The building is constructed of brown Roman brick, with terra-cotta ornaments of the same color. That portion which lies between the three towers is two stories high, with an attic above. The small towers are carried up to a greater height, in order that the large dome may not obstruct too much of the western sky in observations with the small telescopes. Balconies are provided on all the towers, with doors at the cardinal points leading out from the observing rooms. The astron-

omer is thus enabled to command an unobstructed view of the sky at any time while observing.

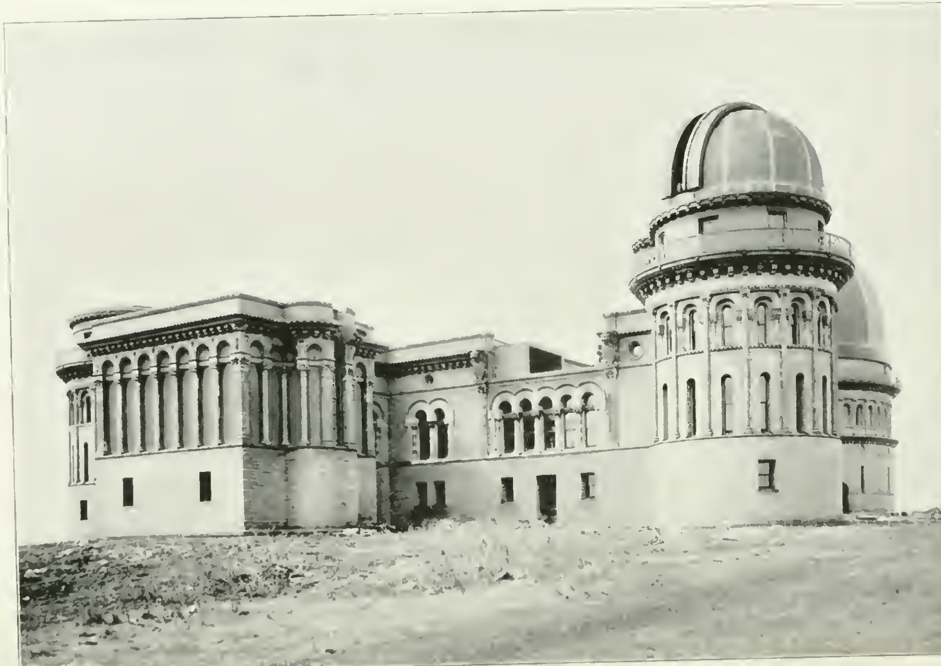
NORTHEAST TOWER.[1]

The northeast tower, thirty feet in diameter, is surmounted by the dome which was formerly a part of the Kenwood Observatory. This dome was built by Warner & Swasey in 1890. The running gear is on the familiar "live-ring" plan, the circular cast iron ring, from which the dome girders spring, resting on the central wheels in fourteen groups of three; the two outer wheels of each group roll on a circular iron track bolted to the stone coping which caps the brick wall of the tower. The groups of wheels are connected together with iron rods, which maintain them at constant positions in the ring. Lateral guide wheels prevent displacement in a horizontal plane. The dome is revolved by means of an endless wire rope, which passes around a ring of angle iron supported just inside of the upper track, and is brought down over guide wheels to a grooved wheel mounted in a recess cut in the south wall of the tower. This wheel is turned by means of an endless rope, hanging in the wall recess within easy reach from the floor of the observing room. The dome is covered with steel plates, bent to form and riveted to the light iron girders and to each other where they overlap. The observing slit, three feet wide, can be closed by means of a double shutter, the halves of which are moved on tracks at top and bottom by racks and pinions, controlled by a wire rope.

Under this dome is mounted the twelve-inch telescope which was formerly at the Kenwood Observatory in Chicago (Plate XIV). The solid brick pier which carries it is in form a frustum of a cone rising from a heavy concrete foundation. The mounting was constructed by Warner & Swasey in 1890, and served admirably for work with the large spectroheliograph of the Kenwood Observatory. It is unnecessary to more than briefly refer to it here. Two twelve-inch objectives by Brashear are provided.

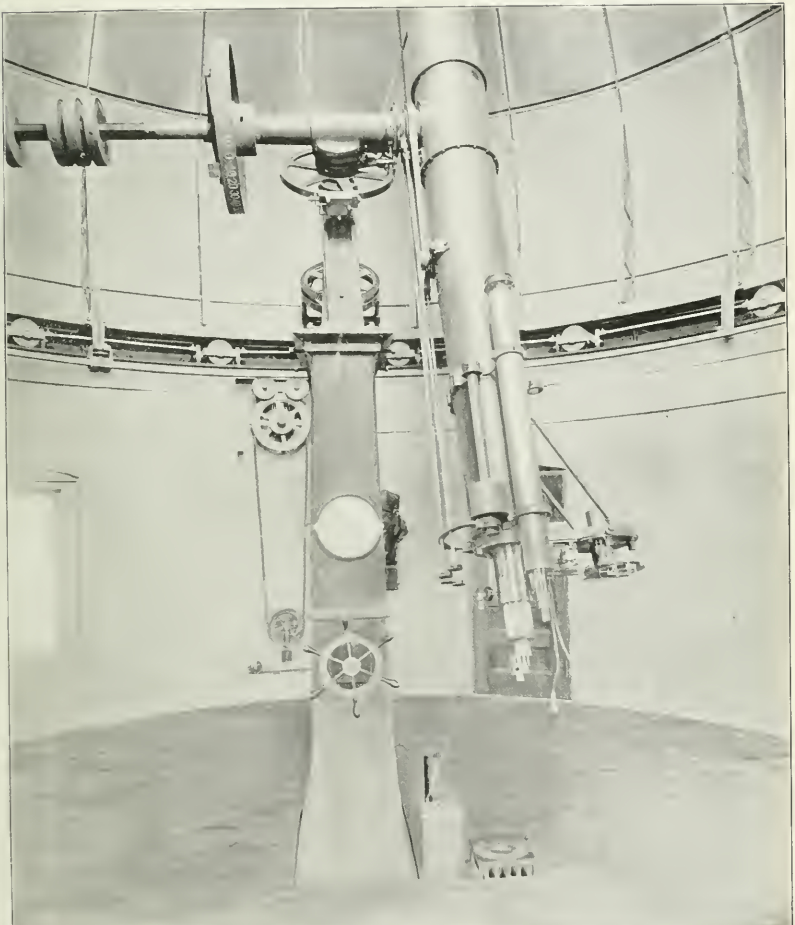
[1] This tower, together with the meridian room and heliostat shutter, are shown in Plate XIII. The small dome has not yet received its final coat of paint.

PLATE XIII.



NORTHEAST WING OF THE YERKES OBSERVATORY.

PLATE XIV.



TWELVE-INCH TELESCOPE OF THE YERKES OBSERVATORY.

For observations with the micrometer only the visual objective is employed, in the usual position at the end of the tube. When it is desired to transform the instrument into a photoheliograph, the photographic objective, mounted in a short tube, is attached to a stout side bracket at the upper end of the steel tube of the telescope. A specially designed rotating shutter, driven by an electric motor, is then clamped to a corresponding bracket at the eye-end, which also carries an enlarging camera. With this arrangement, which will be described more in detail elsewhere, the solar image can be photographed in the focal plane of the objective, or, by the aid of a suitable amplifying lens, enlarged to any scale desired. Means are provided for attaching to the telescope the Kenwood spectroheliograph, which has lately been remodeled in the instrument shop; the stellar spectrograph of the forty-inch telescope; a ten-inch objective grating;[1] and several small grating, prism and direct-vision spectroscopes.

SOUTHEAST TOWER.

The southeast tower is intended for a sixteen-inch telescope, mounted under a dome thirty feet in diameter. This dome has not yet been erected.

MERIDIAN ROOM.[2]

This is constructed on the general plan of the meridian room of the Royal Observatory at Berlin, with double sheet-iron walls and intervening air space, provided with suitable means of ventilation. The room is twenty-eight feet long (exclusive of the projections containing the collimator piers), twenty-five feet wide and twenty feet high. The observing slit is three feet wide, and is covered with a counterbalanced shutter, the sections of which can be easily opened and closed by the aid of small windlasses. A massive brick pier upon a broad foundation of concrete has been built for a meridian circle, and collimator piers have also been provided. For some time to come a transit instrument

[1] See this JOURNAL, 4, 75, 1896.

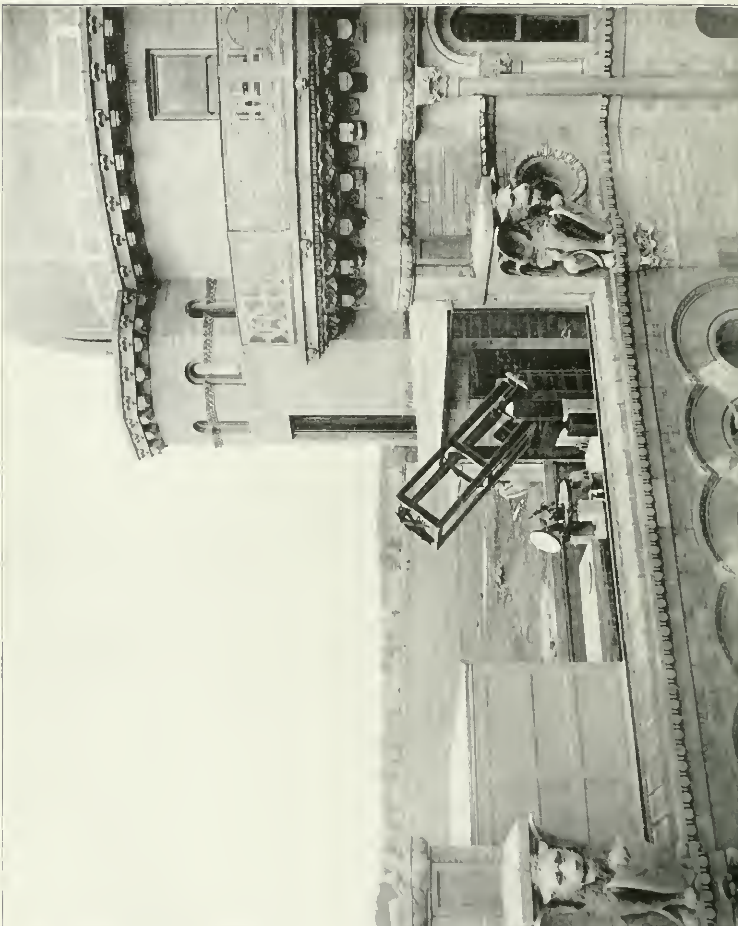
[2] See Plate XIII.

will be used in this room, on a smaller brick pier built in the center of the large pier; but it is intended that this shall subsequently give place to a large meridian circle. The architect has relieved the bareness of the outer sheet-iron walls by the use of a row of columns supporting a rich terra-cotta cornice.

HELIOSTAT ROOM.

An important feature of the Observatory is the heliostat room, which occupies the whole of that portion of the attic floor which lies between the two small towers, a space 104 feet long and twelve feet wide. Twenty-four feet from its northern extremity it is crossed by a double partition, in which are suitable openings for admitting the sunlight. The heliostat (Plate XV) stands on a large brick pier, which rises from the ground at the north end of the room. The iron roof which ordinarily covers it can be pushed away to the south, as it is mounted on wheels rolling on steel rails. It is easily moved by means of a windlass. When the roof is fully withdrawn, the heliostat mirror can receive the rays of the Sun when at its greatest southern declination. That part of the heliostat room which lies south of the double partition is shown in Plate XVI.[1] The walls and ceiling of this laboratory are of sheet-iron, separated from the brick walls and tile roof by an air space. In winter the laboratory is heated by indirect radiation from steam coils in the corners of the unfinished attic rooms. Arrangements are made by which the heated air can be thoroughly dried over unslaked lime as it enters the room, thus greatly facilitating work with rock salt prisms or lenses. The heliostat room contains four piers, the outlines of which are indicated in the plan. Each of these is supported by two separate piers, standing on opposite sides of the hall below, and bound together at the level of the first and second floors with heavy I-beams. The two northern piers are connected to each other and to the

[1] When the photograph reproduced in this plate was taken the apparatus described below had not been set up in the heliostat room. The instrument shown is a large spectroscope, temporarily mounted for the purpose of testing Abney's method of photographing the Sun in monochromatic light.



HELIOSTAT ROOM OF THE YERKES OBSERVATORY (INTERIOR).

heliostat pier with three 15-inch I-beams, which form the essential part of the long pier shown in the plan. All of the piers have smooth slate tops.

The instruments outlined in the plan of the heliostat room are those used by the writer in his attempts to map the solar corona without an eclipse by the aid of a bolometer. Sunlight is reflected from the heliostat mirror to a silvered concave mirror of twenty-four inches aperture and sixty-one feet focal length, made for these experiments by Mr. G. W. Ritchey, optician of the Observatory. The mirror forms an image of the Sun nearly seven inches in diameter in a large cast-iron drum. The sunlight passes through the drum without touching it, and falls upon an amplifier, which forms an enlarged image on a screen. The bolometer is mounted in a radial slot in the drum. The inner member of the pair can be set at any desired distance from the Sun's limb and, by rotating the drum, at any position angle. The outer member is supported at right angles to the inner radial member, and its distance from the limb is constant. An assistant maintains the solar image at a fixed position on the screen by means of the slow motions of the heliostat, and rotates the drum at a signal from the observer, who watches the scale of an extremely sensitive reflecting galvanometer with a telescope. It is desired to determine whether any differences in the heat radiation of the corona can be detected at different position angles. The heliostat at present employed has been loaned to the Observatory by Professor Keeler until the one which is being constructed in our instrument shop is completed. Its mirror has an aperture of seventeen inches. The new heliostat is to have a mirror of twenty-four inches aperture, which is now being figured in our optical laboratory. The new instrument is designed to combine the functions of heliostat and coelostat, in the latter case a second fixed mirror being used with it.

A galvanometer room, provided with a heavy slate shelf to support the instrument, immediately adjoins the heliostat room on the east. The large attic rooms to the west are so arranged that they can also be used in conjunction with the heliostat room.

The entire distance (175 feet) between the heliostat room and the wall of the great tower is available for use with apparatus containing mirrors or lenses of great focal length, etc. .

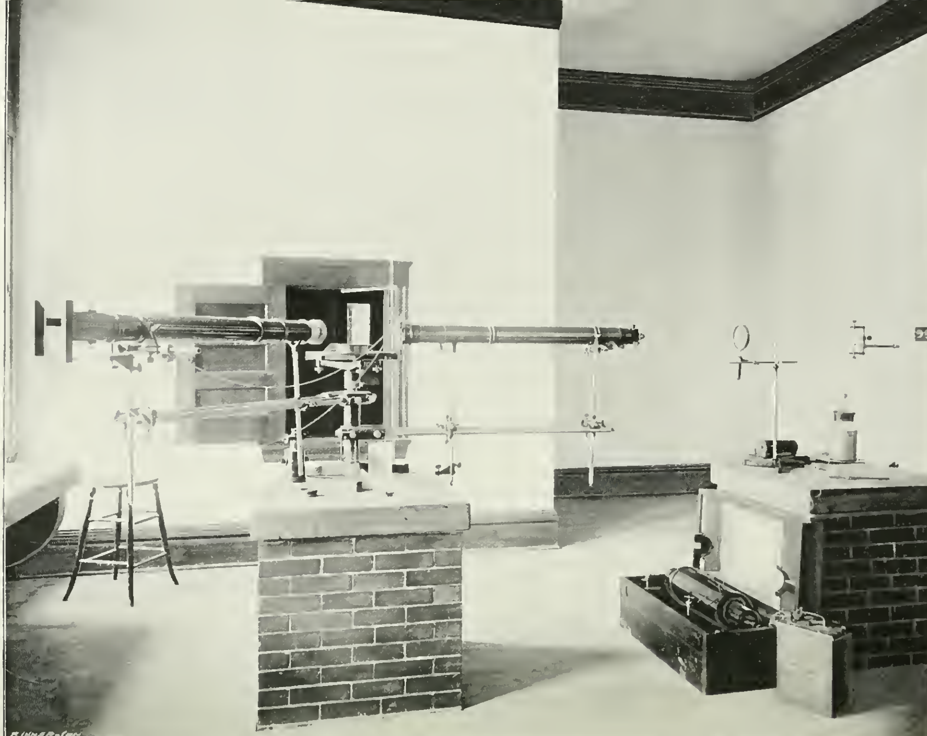
SPECTROSCOPIC LABORATORIES.

The main floor of the building is divided into offices, computing rooms, spectroscopic laboratories, chemical laboratory, instrument rooms, developing room, lecture room, library and reception room. The purpose of each room is indicated on the plan.

The spectroscopic laboratories (Plate XVII) are provided with solid brick piers on concrete foundations, which are arranged with reference to each other and to the doors and windows so that the instruments mounted upon them can be used together, or with heliostats or other apparatus mounted in the open air. In the corner of one of these laboratories is a galvanometer room containing a brick pier and heavy slate wall shelf, specially arranged for bolometric work. Two extremely sensitive reflecting galvanometers are provided. Both of the laboratories have slate shelves, four inches thick, supported by heavy slate brackets built into the outer brick wall. Sinks and running water are also provided, and the windows are fitted with rolling wood shutters, which completely exclude the light when closed. The collection of physical apparatus includes spectroscopes of various kinds, bolometers, galvanometers, interferential refractometers or "wave comparers," induction coils, special electrode holders for spectroscopic work, a Wheatstone bridge, resistance coils, and numerous prisms, gratings, achromatic objectives and mirrors of glass and speculum metal. A small photographic dark room immediately adjoining the spectroscopic laboratories is used in conjunction with them.

CHEMICAL LABORATORY.

The chemical laboratory is fitted with slate shelf, rolling window shutters, sink and running water, and a glass-covered "hood" with suitable ventilation, in which experiments with



SPECTROSCOPIC LABORATORY OF THE YERKES OBSERVATORY.

noxious gases can be performed. It is equipped with a good assortment of chemicals, chemical glassware, balances, appliances for glass blowing, etc.

ENLARGING CAMERA.

In the room adjoining the chemical laboratory there is a large camera, specially designed for copying photographs on any desired scale of enlargement.

INSTRUMENT AND STOREROOMS.

The cases in the instrument room contain a varied collection of instruments and parts which are not needed for immediate use. The room opposite it is intended for general storage purposes; all the wood patterns made in the pattern shop are kept here after being returned from the foundry.

COMPUTING ROOMS.

The two computing rooms are fitted with heavy slate shelves to carry the measuring instruments, one of which, a Zeiss comparator, is already in use. They also contain cases designed for the preservation of the numerous photographic negatives obtained in the course of the Observatory's work. The Kenwood Observatory collection of over 3500 negatives, mainly of solar phenomena, is preserved here for convenient reference.

LIBRARY.

The library is a room 18 by 42 feet, all the available wall space of which is covered with oak bookcases, having shelves above and cupboards below. The librarian's office, provided with an iron vault for the storage of valuable papers, immediately adjoins it. The collection of books is at present far from complete, but important additions are constantly being made. The thanks of the Observatory are due for the valuable contributions which have been received from individuals and scientific institutions in all parts of the world. Some fifty different scientific periodicals are regularly received by the library. On

account of its isolated position, removed from the reference libraries of Chicago, it is of the highest importance that the collection of books be made as large and complete as possible. It goes without saying that all contributions of scientific publications have been exceedingly welcome.

The Observatory possesses a large and increasing collection of photographs, including those exhibited by the Royal Astronomical Society at the Columbian Exposition, and afterwards presented to the Observatory; a complete set of glass positives from Professor Barnard's portrait-lens photographs of the Milky Way, comets and nebulæ; and the Kenwood Observatory collection.

RECEPTION ROOM, OFFICES AND LECTURE ROOM.

The reception room for visitors opens out of the central rotunda.

Several rooms on the main floor are used as offices by members of the staff, as indicated in the plan (Plate X).

At one end of the long corrider is a lecture room, containing a large blackboard.

CONCAVE GRATING ROOM.

The floor below is reached by stairs at both ends of the building. The eastern half of this lower story is devoted to the optical laboratory and the instrument and pattern shops, which, with the power house, will be described in another article. The western half contains the concave grating room, physical laboratory, constant temperature room, emulsion room, enlarging room, and photographic dark rooms. The concave grating room is specially designed to contain a concave grating of twenty-one feet radius, mounted in the ordinary manner. The instruments at present used are a four-inch concave grating of ten feet focus, and a smaller one of six feet focus, from the Kenwood Observatory collection. The three brick piers, with slate tops, which carry the mounting, are shown in the plan (Plate XI). The slit is at *S*, the grating at *G*, and the plate-

holder or eyepiece at *P*. Sunlight is reflected into the room from the mirror of a heliostat placed outside the window, a lens being interposed to form an image of the Sun on the slit. An image of an electric arc or other light source may also be formed on the slit, either by placing the light in the direction from which the sunlight comes, or to one side, a reflecting prism being employed in the latter case. A window has been cut in the partition which separates the concave grating room from the adjoining physical laboratory, and the centers of the piers in this latter room are in line with the rail on which the plate carriage moves. Thus any desired apparatus can be used in conjunction with the concave grating. Both rooms have rolling wood shutters, which effectually exclude the light. The physical laboratory is also provided with heavy slate shelves and an instrument case. The piers in this room have been found to be extremely steady, the most sensitive galvanometer showing no signs of vibration due to the machinery in the instrument shop. A variety of minor apparatus, consisting of a large Apps induction coil, mercury pump, oxy-hydrogen burners, arc lamp, special electrode holders for spark spectra, Geissler tubes, etc., from the Kenwood Observatory collection, is available for use with the concave grating, or in the other laboratories. The concave grating room is reached from the central hall through a passageway having both outer and inner doors. Thus the room may be entered at any time during a long exposure without danger of admitting light and fogging the plate.

EMULSION ROOM.

In one corner of the concave grating room is the "emulsion room," fitted with sink and running water for photographic purposes. The walls and ceiling are painted black, and can be sponged perfectly free from dust when photographic preparations requiring very careful treatment are to be made. This room can also be entered from the central hall without danger of admitting light.

PHOTOGRAPHIC DARK ROOM.

The large photographic dark room is on the north side of the building, opening into the central hall through a double door. It is divided into three stalls, two for developing and one without sink or water for use in changing plates. Each stall is supplied with numerous shelves, and each has a ventilated recess in the wall fitted with a swinging door glazed with red glass, designed to contain the electric or oil lamp used for illumination. Immediately adjoining the developing room is a room for fixing and washing plates. Two sinks are provided, one to contain "hypo" tanks for plates of various sizes, the other for the washing tanks. The outside windows of this room are glazed with red glass, and admit much more light than would be safe in a developing room, but not too much to affect the plates before and during their immersion in the hyposulphite bath.

ENLARGING ROOM.

The small room next to this contains a photo-engraver's arc-lamp, for enlarging and copying photographs by electric light. A pair of large condensers are fitted into an opening in the partition, and within there is a frame for supporting the negative. Beyond this is the enlarging lens, which projects the image upon a screen mounted on rollers, which can be set at any desired distance (up to twenty-four feet). All of these rooms are provided with rolling wood shutters, which can be instantly opened or closed. The walls and ceilings are painted dark red. The developing and washing rooms have cement floors.

CONSTANT TEMPERATURE ROOM.

On the opposite side of the long hall is the constant temperature room, which has double walls with intervening air space and double doors. This room contains two clock piers, and a brick pier with large slate top for experimental work which must be carried on under conditions of constant temperature. The only astronomical clock yet in place is a fine Howard clock from the Kenwood Observatory.

All of the rooms of the Observatory are connected with boxes running along the ceiling of the lower story, through which electric wires can be drawn. The building is lighted throughout by incandescent electric lamps, and heated by steam. A system of telephones places the Director's office in communication with the three domes and the power house. But little wood was used in constructing the Observatory, the walls being of brick and terra-cotta on concrete foundations, the partitions of hollow tile, and the floors and roof of tile supported by steel I-beams. The floor of the long hall in the main story is of marble mosaic, and the walls are wainscoted with marble. The offices and laboratories have maple floors, and oak is used throughout the building for the doors and other wood finish.

PORTRAIT LENS AND COMET SEEKER.

A circular building ten feet in diameter, surmounted by a light steel dome having a very broad slit, has been erected on the Observatory grounds about 300 feet southwest of the great tower. This will contain an equatorially mounted portrait lens for photographing comets, the Milky Way, nebulæ, etc. A comet seeker will be established at no great distance from this dome.

REFLECTING TELESCOPES.

The Observatory will have the use of two large silvered glass reflecting telescopes. One of these, of twenty-four inches aperture and eight feet focal length, which was made by Mr. Ritchey for photographic work, is already employed for visual observations, on a temporary mounting in the heliostat room. The sixty-inch mirror of the other instrument, which is to be mounted as an *equatorial coudé* for astrophysical investigations, will soon be figured in the optical laboratory.

YERKES OBSERVATORY,
March 1897.

(*To be continued.*)

THERMAL MEASUREMENTS WITH THE BOLOMETER BY THE ZERO METHOD.

By F. L. O. Wadsworth.[1]

In the May number of the *Annales de Chimie et de Physique*,[2] in an article entitled "Sur le Bolometer," M. Crova describes what may perhaps be termed a zero method of using the bolometer, for which he claims a number of advantages. The arrangement which he proposes is only a modification of the well-known form of slide wire bridge which is now so universally used in the exact measurement and comparison of standard resistance coils, and the credit for any novelty which there may be in its application to the purpose for which he designs it belongs, I think, to Dr. Hallock, my predecessor in the Observatory, who first used it in the winter or early spring of 1892, over a year before the publication of M. Crova's paper.

When I was placed in charge of the work at the Observatory in October of the same year, I modified the existing arrangement, with a view to securing a more sensitive and reliable action, by substituting for the single balancing wire of copper two much larger wires of platinoid, which were stretched side by side about 1^{cm} apart, as shown at $a\,b$, $a'b'$, Fig. 1. The inner one was connected to the terminals of the bridge ab; the other one to one of the battery terminals, and a sliding clamp c used to connect the two. All movable wires were thus avoided and a smoother motion and better contact secured for the balancing

[1] Then Senior Assistant (in charge) of the Astrophysical Observatory, Washington, D. C.

[2] The main part of this paper was written, as may be seen by the appended date, over three years ago, or only a few months after M. Crova's article appeared. On account of pressure of other work it was laid aside and forgotten, until in looking over my papers a few days ago, I came across it. Although it is now considerably out of date as a reply to M. Crova's article I have been requested to publish it as it stands, although I hope before long to treat the whole subject of bolometric work in a more complete and satisfactory manner.

clamp. The wires were about 2^{mm} in diameter, and the change of resistance per millimeter of length was therefore

$$R = s\frac{l}{\pi r^2} = \frac{0.33 \times 10^{-5}}{0.0314} = \text{only } 0.0001 \text{ ohm.}$$

I soon found, however, that even this was far too large a rate of change for exact measurements, for with the new galvanometer

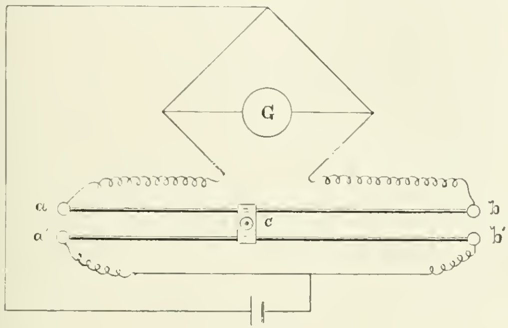


Fig. 1

which had in the meantime been constructed for the work,[1] the bridge system was so delicate that a movement of less than 0^{mm}.1 caused a galvanometer deflection of more than a hundred divisions on the scale, and since the deflection could be read to a tenth of a division, it was at once evident that with this arrangement the accuracy of the zero method, even supposing that the position of the slider could be determined to 0^{mm}.01, would only be about $\frac{1}{100}$ as great as the direct reading of deflections. In order to attain the same degree of accuracy, a balancing wire would have to be used having a cross section at least one hundred and probably one thousand times as great (since movements smaller than $\frac{1}{10}$^{mm} can hardly be relied upon with any form of sliding contact). This would

[1] A description of this instrument appeared in the *Phil. Mag.* for December 1894.

have meant a wire over 60^{mm} in diameter, which was of course quite out of the question as a practical arrangement. This form of balance was therefore discarded and the one shown in Fig. 2 was, after some study, adopted in its place. In this we have the same two platinoid wires, $a\,b$, $a'b'$; the terminals $a\,b$ being connected to the bridge terminals as before, and the terminals $a'b'$ of the second wire being now connected by means of flexible copper conductors of small resistance to two movable clamps m, n, on the first wire. A third clamp o connected to the battery terminal slides upon the wire $a'b'$ The theory of this arrangement (which is simply a modified form of shunt), is as follows:

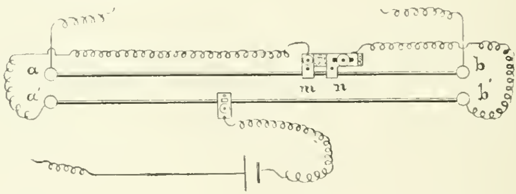


Fig. 2

Let x (Fig. 2) be the resistance of that portion of the wire $a\,b$ between the two clamps $m\,n$; p the resistance of that portion of the wire $a'b'$ from o to a'; q that of the wire from o to b', and R and R' the resistance from m to a and n to b respectively.

Then we have:

Total resistance o to a (left hand bridge terminal),

$$R_{oa} = R + \frac{1}{\frac{1}{p} + \frac{1}{q+x}} = R + \frac{p\,(q+x)}{p+q+x},$$

and total resistance o to b (right hand bridge terminal),

$$R_{ob} = R' + \frac{q\,(p+x)}{p+q+x}.$$

But R and R' may be considered simply as forming parts of

the bridge arms P, Q; and hence, when the bridge is in balance, $P + R = Q + R'$, and, therefore,

$$R_{oa} - R_{ob} = \frac{(p - q)\,x}{p + q + x}.$$

Let y be the distance of the clamp o from the center of the wire, and let l be the whole length of the wire $a'\,b'$. Then, if r_o is the resistance per unit length,

$$r_o\,y = p - q \quad \text{and} \quad r_o\,l = p + q,$$

$$\therefore\ R_{oa} - R_{ob} = r_o y\,\frac{x}{r_o l + x}.$$

In the previous arrangement the change in resistance between the two arms of the bridge produced by moving the balancing clamp a distance y was simply $2\,r_o y$.

With the new arrangement the change in resistance for a given motion y has, therefore, been reduced in the ratio

$$\frac{x}{2\,(r_o l + x)}, \quad \text{or nearly} \quad \frac{x}{2\,r_o\,l},$$

if x is small as compared to l.

The second wire evidently plays the same part with respect to the first that the eyepiece of a telescope performs for the objective. The eyepiece magnifies the image formed by the objective in the ratio $\frac{f}{f'}$, while the wire $a'b'$ magnifies the motion of o in the ratio $2\frac{r_o l}{x} = 2\frac{l}{\overline{mn}}$, if the wires $a\,b$ and $a'b'$ have the same resistance per unit length. In the actual arrangement l was about 40^{cm}, and the distance $\overline{mn}$ was 1^{mm}. The magnification was, therefore, 800, or the system was equivalent to a single balancing wire having a cross section 800 times as great as that of the wires used. By making x still smaller, either by decreasing the distance mn or increasing the size of the wire ab, still greater magnification may, of course, be easily obtained, and the errors, due to inequalities in the size of the wire $a'b'$ and uncertainty as to the exact point of contact of the balancing clamp o with the latter, made as small as we choose. This arrangement, therefore, both on account of this greater sensitiveness and also on account of its greater compactness for

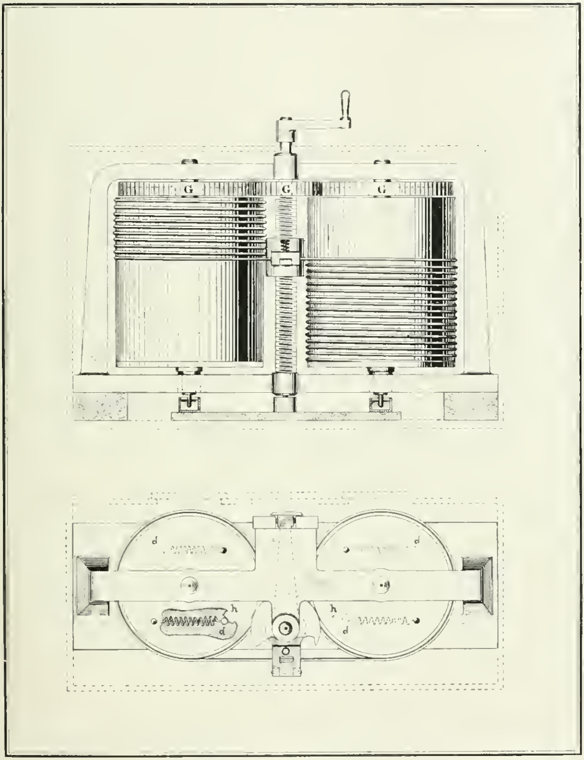
a given range of resistance, is far better adapted to accurate measurements by the zero method than the usual single-slide wire, and since, as we have just seen, the change of resistance is directly proportional to the linear movement of the balancing clamp or slider c, it is equally as convenient to use.

When the magnification is high the rate of variation of resistance along the wire $a'b'$ is, of course, low, and in order to obtain a considerable range the latter would have to be of considerable length.[1] In this case a very compact and convenient mounting for the second wire $a'b'$ is a modification of Thomson's drum rheostat which I have designed for this work and which is shown in plan and side elevation in Plate XVIII. The wire is wound, as shown in the plate, on two accurately turned ebonite cylinders,[2] which are geared together at one end by means of spur wheels G, G, G, so as to turn in the same direction with the same angular velocity. The ends of the wires are permanently attached to a heavy brass plate at the lower end of the cylinders and the sliding clamp, o, is carried on a copper screw s, which is driven by means of the intermediate gear G at a speed about twice that of the drums. The pitch of this screw is such that the clamp, o (which serves also as a guide for the wire, as it winds from one cylinder onto the other), moves a distance equal to about the diameter of the wire for every revolution of the screw. Continuous connection is made with the two plates with which the ends of the wire are connected by means of two attached copper wires which revolve in mercury cups, connected to the clamps m, n of the bridge system; and

[1] So far as a range of resistance is concerned, this is furnished by a movement of the two clamps m, n, either independently or together along the wire ab. But the accuracy of the determination of the change of resistance is in this case limited, just as in the case of the single-slide wire arrangement, by the accuracy of the determination of the position of the clamps m, n. It is well to have these movable in order to effect a preliminary adjustment of the bridge arms to approximate equality, and for this purpose it is convenient to have them so mounted on a single block of hard rubber (Fig. 2), that while they may be shifted slightly with respect to each other (in order to change the magnification if desired), they may usually be moved together as a unit along the wire ab.

[2] Brass covered with a thin sheet of ebonite would be better.

PLATE XVIII.



DRUM RHEOSTAT FOR BOLOMETRIC MEASUREMENTS.

connection is similarly established between the clamp *c* and the battery circuit through the copper screw *s*, the lower end of which revolves in a third mercury cup.[1]

The position of the slider with reference to one end or the center of the wire (or with reference to any intermediate point which may correspond to the initial zero of the bridge), is determined by means of a scale engraved on the guide in which the tail piece of the clamp, *o*, slides, and a graduated head on one of the drums; the former giving the whole number of turns and the latter the fractions of a turn of the drums; from which, when we know the diameter of the cylinders and the pitch of *s*, the length of wire wound from one to the other may be at once determined. In order to keep the wire under a constant tension and thus make the winding as smooth and regular as possible, the large gears are left loose on the shafts of the drums and are only connected with the latter by means of strong spiral springs, as shown in Plate XVIII.[2] In order to keep the wire at a constant temperature the whole arrangement may be immersed in a bath of oil, but it usually suffices to simply enclose it in a wooden box (as shown by the dotted lines), provided with a glass window through which the position of the slider may be read on the scale and graduated head. The minor details of construction may be easily understood from an inspection of the drawings themselves.

As regards the comparative advantages of the two methods (the deflection and the zero method) of measurement it is possible to institute only a very general comparison. The process of making thermal measurements with the bolometer is, it is true, only a process of making a series of measurements of

[1] To avoid any connection between the two ends of the wire the bearings in which the drum axles turn are mounted in rubber bushings and the gear on the screw is made of rawhide or vulcanite fiber.

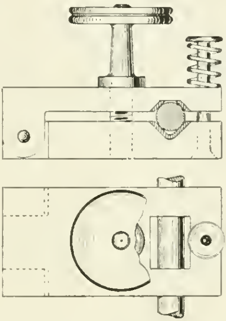
[2] A more accurate method of determining the position of the slider on the wire, which has recently suggested itself, is to make the latter in the form of a thick tape which is graduated on its upper surface. This would entirely avoid any errors due to irregularities in the winding or in the surface of the drum, or to changes in the tension of the wire.

resistance, and from that point of view alone the zero method would have the same advantages which attend its use in the accurate comparison of resistance coils by the slide wire bridge. The zero method has also a much wider range than the method of deflections, and if we wished to directly compare the radiation from two sources of energy, one of which is several thousand times as intense as the other, the former would be much more direct and perhaps also more accurate than the latter, which would necessarily involve the use of shunts.

On the other hand the method of deflections is much more expeditious and more readily admits of a continuous registration of the variations in the intensity of radiation falling on the bolometer strip, if these variations are not too large. It has also the advantage of involving no disturbance of contacts in any part of the bridge circuit, an advantage of so much importance when the bolometer is in its highest state of sensitiveness, that it practically excludes the employment of the zero method for accurate measurements of very feeble radiations. The reason for this is not at first apparent, for since the only sliding contact is at one of the battery terminals it would seem at first sight that any slight variation of resistance at that point would affect both arms of the bridge alike, and leave its balance undisturbed. But observation shows that any such variation (even when very small indeed) does affect the balance of the bridge very considerably, and the reason for this is that it causes a minute change of resistance and therefore a minute change of current in the battery circuit. In order to avoid this effect as far as possible many forms of sliding contact were tried. What is needed is something that can be easily slid along the wire, and at the same time can always be relied upon to maintain good contact. A sliding mercury contact is one of the first things that suggest themselves for this purpose, but none have been found that can be relied upon for any length of time. The best arrangement so far found is one similar to that shown in Fig. 3. It consists simply of two brass plates hinged together at the back and held together at the front

by a strong spiral spring. The wire lies in two V grooves lined with platinum, and cut away in the center in order to insure two perfectly definite points of contact at the ends. A screw is added to secure the clamp in place at any desired point on the wire. The clamp through which the wire passes in the case of the drum mounting already described is exactly similar in character.

Fig. 3



The effect of a small change of current in the bridge has not been considered, nor as far as I know even mentioned as a source of difficulty by those writers who have described most fully the manipulation of the bolometer, and I may therefore consider it, together with some other points of importance, more in detail in a subsequent paper.

Suffice it to say here, that in some of the earlier forms of bolometer (I have in mind particularly those designed and used by Mr. Langley in his thermal measurements in the infra-red spectrum at Allegheny, 1881–6),[1] a variation in the strength of the battery current of only one part in 1000 ($\frac{1}{10}$ of 1 per cent.), would produce a difference in the temperature of the two strips

[1] Described by Mr. Langley in the *Proceedings of the American Academy of Arts and Sciences*, **16**, 342, 1881.

of considerably over a tenth of a degree, or a difference a thousand times as great as that produced by the feeblest radiations which could be measured. This relatively enormous change in this case is due in large part to some radical errors in the design of these bolometers. With a properly designed and well constructed instrument this effect is reduced at least a hundred times, but it remains even then relatively large to the effects which are to be measured, and becomes of greater and greater importance as the delicacy of the whole system is increased. It alone is sufficient to account for nearly all the phenomena of bolometric "drift" which has been heretofore attributed to gradual changes in the temperature of the surroundings, or to changes in the amount of energy falling on the bolometer strip caused by changes in the atmospheric absorption.[1]

Smithsonian Astrophysical Observatory,
Washington, D. C., July 1893.

[1] That this latter explanation at least is very far from the true one is seen readily enough from the fact that the drift observed is often many times as great as could possibly be occasioned by the cause in question; many times greater, in fact, than that produced by changes in the radiation equal to the total amount falling on the bolometer strip.

Minor Contributions and Notes.

NOTE ON PROFESSOR CAMPBELL'S OBSERVATIONS OF NOVA AURIGAE.[1]

In *A. N.*, No. 3238, **135**, 386–390, I have given a long series of measures of the position of *Nova Aurigae* with reference to two comparison stars, *E* and *F*. These measures were made at Mt. Hamilton with the thirty-six-inch to detect parallax or motion, neither of which were shown to exist. In this paper I have the following note on the appearance of the *Nova*, which, from his remarks above, Professor Campbell seems to have overlooked.

"Much has been said of late in regard to the nebulosity of the *Nova*. Dr. Huggins, Dr. Vogel, and Mr. Newall think it is simply a telescopic effect.

"For my own part I am anxious to do all I can to settle the question, as I was instrumental in getting it started. I will therefore state all I have learned about this nebulosity. I have no theory whatever to defend, and simply wish the truth to be known, and if my observations can be of any service in getting at the true condition of this wonderful object I shall be satisfied.

"When I examined this star on August 19, 1892, it appeared to me to be densely nebulous, and since then it has not appreciably changed.

"The comparison star *F* is yellowish, while the *Nova* is bluish white. These two extremes of the spectrum make quite a difference in the focus for the two objects, as has been pointed out by Mr. Newall in his experience with the twenty-five-inch at Cambridge. This amounts to $\frac{3}{10}$ of an inch with the thirty-six-inch, and the *Nova* comes to a focus outside of that for *F*. When the *Nova* is in the best possible focus it is hazy and surrounded for $5''$ or $6''$ with a decided nebulosity. Now when *F* is in focus there is no such glow about it, nor is there about any of the other stars near.

"How much of this nebulosity is due to the peculiarity of the spectrum of the *Nova* I am not able to tell. But from my experience with nebulæ I would unhesitatingly say that the *Nova* is distinctly and

[1] See p. 240

unquestionably nebulous. It seems to me that Dr. Huggins' examination of this object with a large reflector — if he uses a high enough power — is the fairer test, as no peculiarity of refraction would enter into the formation of its image. To me the star is nebulous when in perfect focus both with the thirty-six-inch and the twelve-inch. As I have said, whether this is an effect of some peculiarity of its spectrum or not I am unable to tell.

"The following will cover the apparent phenomena: When the *Nova* is in perfect focus it is hazy or woolly, the image fading into a nebulous glow some $5''$ or $6''$ in diameter. Under this condition F is surrounded by a disk of light several seconds in diameter and slightly yellowish. When F is in perfect focus it is clear cut and sharp, with no traces of a nebulous glow about it: the *Nova* is then surrounded by a similar mass of light to that previously shown by F, except that it is whitish.

"When I examined the *Nova* on August 19, 1892, I stated that it was apparently nebulous before I knew of any spectroscopic or other observations indicating a nebulous condition."

MT. HAMILTON, April 9, 1894.

I have nothing to add to or to subtract from the above statement, further than to say that on the morning of August 20, 1892, both Professor Campbell and myself independently announced to Professor Holden that this star was nebulous, from the previous night's observations, one with the spectroscope and the other visually, and each without knowing of the work of the other. Indeed I knew nothing of the spectroscopic observations until the evening of August 20.

A continuation of my measures of the position of Nova Aurigae, referred to above, will be found in *A. N.*, No. 3279, **137**, 233.

E. E. BARNARD.

YERKES OBSERVATORY,
March 21, 1897.

ERRATA.

The following corrections should be made in Professor Harzer's article in the January 1897 number of this JOURNAL:

Page 36, second line from the top, for *vigor* read *rigor*.

Page 37, for Δ read 1 (three times).

DR. ARENDT'S SPECTROSCOPIC INVESTIGATION OF THE VARIATION OF AQUEOUS VAPOR IN THE ATMOSPHERE.[1]

In the review by Professor E. B. Frost in the February number of the Astrophysical Journal, of Dr. Arendt's paper on the spectroscopic observation of variations of the amount of aqueous vapor in the atmosphere, there is a very serious error which should be corrected.

The statement is made that the increase in intensity of atmospheric lines in the spectrum is proportional to the increase in path. Probably what is meant is that the increase in intensity is as the increase in amount of atmosphere traversed by sunlight. But this statement not only supposes that the character of the distribution of aqueous vapor in the Earth's atmosphere is the same as that of the other gases, which is very far from being true, but that the increase in intensity of absorption should be as the increase in the amount of the absorbing gas traversed by sunlight, which is directly contrary to the law of absorption in which the absorption factor enters as an exponential term.

In my paper[2] it was thought best not to enter into these matters to any great extent, but this subject was carefully investigated and the value of the absorption factor for oxygen lines was determined, and the theoretical values of the intensity of oxygen lines at different altitudes of the Sun were calculated and compared with the results of observation, and they were found to agree within the limits of errors of observation.

In the case of water-vapor, the absorption factor was determined only approximately by an indirect method which consisted in plotting together the intensities (reduced to the standard condition of the Sun in the zenith), for a large number of days, when complete series of observations were secured, and the absolute humidity for those days. The result was not a straight line but somewhat of a curve, as it should be according to absorption laws; but any such determination can be but unsatisfactory because of the probable difference in the character of the distribution of aqueous vapor in the atmosphere during warm and cold weather.

[1] "Die Schwankungen im Wasserdampfgehalte der Atmosphare auf Grund spectroskopischer Untersuchungen." Th. Arendt, *Wied. Ann.* 58, 171–204, 1896.

[2] *Ap. J.* 4, 324, 1896.

It was also shown by the investigation that if the absorption be supposed to increase proportionately with the amount of vapor traversed, no possible method of distribution of aqueous vapor in the atmosphere will give results agreeing with those of observation, while if the value of the absorption factor found be taken, then rational methods of distribution of aqueous vapor in the atmosphere will give results agreeing fairly well with observations. But the character of the distribution not only varies very greatly with the season, but is vastly different from that of the oxygen and nitrogen in the atmosphere, except during the prevalence of cold waves, when there is considerable resemblance. As this work was very laborious, and it was hoped before long to obtain special observations which would give accurate data for determining the value of the absorption factor for aqueous vapor free from the uncertainties of indirect methods, these comparisons were only carried out far enough to get a good idea of the facts in the case.

Professor Frost is mistaken in supposing that Dr. Arendt's method of comparing atmospheric and solar lines was different from mine. The method which he used (in 1895) was used by me during 1892 and 1893, and the method of comparison, together with a description of a photographic scale for determining the relative intensity of the solar lines used for comparison, and some of the results of observation obtained, were described in a paper read by Dr. J. S. Ames at the Congress of Astronomy and Astrophysics in Chicago, August 1893, and published in *Astronomy and Astrophysics* for November 1893.

The essential difference in the methods pursued by Dr. Arendt and myself were that I carefully determined the intensities of the solar lines used for comparisons by the aid of a photographic scale, the lines of which varied uniformly in intensity according to an exact law, and which closely resembled in appearance the spectrum lines which were measured.

In observations of the oxygen lines comparisons were made with selected solar lines (the intensities of which had been determined by the photographic scale) and also directly in the spectroscope with the lines of the scale, and the two methods gave concordant results. Some observations of the water-vapor lines have also been made in the same way, and as a result of comparison of the two methods, I can say that a direct comparison with the lines of the scale gives far more accurate results and is much more simple and satisfactory in every way. However, measurements of three or four solar lines of different intensity

should be made at the same time to obtain the slight corrections which are necessary where the width of the slit does not remain constant.

Had all of my observations been made in this direct way, greater accuracy would have been secured and an enormous amount of time and labor in the work of reduction would have been saved.

For determining the intensity of the comparison solar lines, Dr. Arendt's method of intensity steps gauged by the eye alone is certainly far from satisfactory where much accuracy is desired, as it is little better than guess-work, for the eye is quite unreliable for estimating how great differences in intensity are, though quite accurate for determining equality.

The principal reason why a spectroscope is not to be recommended as an addition to the instrumental equipment of all meteorological stations for prediction purposes, is that a set of observations, from sunrise to noon or from noon to sunset, is necessary for determining the data desired ; or if observations are confined to those made near the meridian, they may not be strictly comparable with the meteorological observations which are made in the morning and evening, and in point of time are not available for prediction purposes. At selected stations, however, meridian observations might be of value.

However, for purposes of studying the distribution and amount of aqueous vapor in the atmosphere, I believe the spectroscope is capable of giving much valuable and readily secured data, after the value for the absorption factor of aqueous vapor has been determined. Plans have been made which it is hoped will lead to the securing of this data before very long.

LEWIS E. JEWELL.

JOHNS HOPKINS UNIVERSITY,
March 10, 1897.

Reviews.

PHYSICAL PROPERTIES OF X-RAYS.

Although many new properties of these rays have been discovered during the past year, as yet no crucial experiment has been brought forward to decide whether they are longitudinal or transverse waves, or streams of material particles like the cathode rays. That they are streams of material particles is, however, unlikely in view of the experiments of Minchin and Threlfall. The ulcerations of the skin and injurious effects on the joints, which have resulted, in some instances, from long continued exposure to the Röntgen rays, have probably no connection with these rays, but may be due to the cathode rays outside the tube. The possibilities of longitudinal vibrations in the ether have been discussed by Professor J. J. Thomson (*Proc. Phil. Soc., Cambridge*, Vol. IX, Part II) in which he shows that when convection currents exist, the condition for the vanishing of the longitudinal wave is not satisfied, and in this case we may have longitudinal waves. These conditions exist in a vacuum tube, and would even exist in solid dielectric media, provided each molecule were made up of a pair of oppositely charged atoms. The necessary condition for the production of these waves being (1) that we should have means of producing waves whose length is comparable with molecular distances and (2) that we should be able to set the ether in motion. Both convection and longitudinal dielectric waves require for their propagation the presence of matter-carrying charges, for on Maxwell's electromagnetic theory the longitudinal wave could not be propagated in ether free from matter.

On the other hand, Professor Thomson (B. A. Address, *Nature*, September 17, 1896) has called attention to the fact that nearly every property of these rays is possessed by some form or other of light. For instance, many of the properties of these rays are possessed by a radiation emitted by the uranium salts and other fluorescent substances. This new radiation, which was recently discovered by Becquerel, is undoubtedly light, as it can be polarized. So far, the two essential properties of light waves, refraction and polarization, seem

to be absent from the Röntgen rays; but the absence of refraction is not uncommon even in ordinary light. As we know from the experiments of Kundt, Pflüger, and others, certain waves can pass through gold, silver, copper, and the aniline dyes without experiencing any refraction, while other waves are bent in the wrong direction. Professor Thomson also calls attention to the fact that according to our theories of dispersion we should not expect to find any refraction if the frequency of these waves is very great. Thus, on the Helmholtz dispersion theory, which is based on the assumption that a molecule of the refracting substance is composed of two oppositely charged atoms and that the specific inductive capacity of the medium may be considered as made up of two parts, one due to the ether itself, and the other to the setting of the molecules along the lines of electric force, we should find that the index of refraction increases with the frequency of the light waves until it is equal to the natural period of vibration of the molecules of the refracting substance. The index of refraction then diminishes, becomes less than unity, and finally approaches unity, as the period of the light waves becomes great in comparison with the free period of the molecules. The relation between the refractive index and the frequency is shown by the following consideration: Let a force of given amplitude act on a mixture of such molecules as are considered in the Helmholtz theory and which have but one natural period of vibration. Then beginning with a frequency of force less than that of the substance, the index of refraction will increase with the increase in the frequency of the force, because the specific inductive capacity increases, due to the fact that more and more of the molecules will swing into line; the effect of the force will be greatest when its period is equal to the natural period of the molecules. After this, as the period of the force becomes greater than the natural period of the molecules, they will topple over so as to oppose the specific inductive capacity due to the ether. If there are a sufficient number of molecules they may overcome the specific inductive capacity due to the ether, so that the specific inductive capacity of the mixture will be negative. Waves of this frequency could not, of course, traverse the medium, but would be totally reflected. Then, as the frequency of the force increases, the effect of the force in making the molecules set will be less and less, and finally the negative part of the specific inductive capacity of the molecules will equal the positive part due to the ether. The index of refraction will then be zero. After this the effect of the

force growing less and less with increase in frequency, the specific inductive capacity approaches that due to the ether alone, *i. e.*, unity.

So far the only experimenters who have obtained any evidences of polarization are Prince Galitzine and Karnojitsky (*C. R.* **122**, pp. 717–718, 1896). By a sort of cumulative method they thought they could observe slightly greater absorption with the axes of the tourmaline plates crossed than when the axes were parallel, but these experiments are uncertain and have not been confirmed by other observers. The reason we have not been able to detect any evidences of polarization may be due to the fact that we have not used polarizers of sufficiently fine structure. Long electric waves may be polarized by a very coarse wire grating; DuBois and Rubens succeeded in polarizing the infra-red rays by means of a fine wire grating; while shorter waves would require a very much finer structure.

Thus the absence of polarization and refraction cannot be urged as evidence against the theory that the Röntgen rays are transverse ether waves, but is rather what we should expect if these are very short waves. If the atoms of a vibrating molecule carry an electrical charge, then the electromagnetic theory of light would lead us to expect two kinds of waves, one due to the oscillations of the atom, the other due to the oscillations of the electrical charges carried by these atoms. The wave-length of the latter would be comparable with atomic dimensions. Professor Thomson asks: "Can these be Röntgen rays? and if so we should expect them to be damped with such rapidity as to resemble electrical impulses rather than sustained vibrations."

Professor Stokes thinks (*Nature*, p. 427, 1896) that the many properties which the Becquerel rays have in common with the Röntgen rays almost establishes the fact that the Röntgen rays are due to some kind of transverse vibration. He regards the disturbance as non-periodic, though having certain features in common with a periodic disturbance of very great frequency.

Nearly all observers who have studied the reflection of Röntgen rays were unable to detect any evidence of regular reflection. The only observer who has obtained any result indicating regular reflection is Lord Blythswood (*Proc. R. Soc.*, March 1896). He used two mirrors of polished speculum metal placed side by side to reflect the rays. The negative on development appeared to show the crack separating the mirrors. It may be worth while repeating the experiments using mercury as the reflecting surface. The diffuse reflection may be due

to the fact that surfaces which we regard as highly polished and which reflect waves of ordinary length, may in reality be extremely rough for these very short wave-lengths, or else it may be due, as Stokes suggests, to a kind of phosphorescence produced in the substance of the mirror. The latter view would seem to be supported by some experiments of Thomson in which the reflected rays appear to have different properties (as regards the discharge of electrified bodies) from the incident rays.

M. Gouy (*Jour. de Phys.* 3^e série, t. V) in his researches on the refraction and diffraction of the Röntgen rays made use of a form of tube called focal, in which the rays take rise at the surface of a thin plate of platinum placed at the center of curvature of a spherical cathode. The Röntgen rays which start from this flat lamina have a nearly equal intensity in all directions, down to the plane of this lamina. By working thus at very nearly grazing angle he obtained practically a linear source of great intensity, and was thus enabled to place his photographic plate at considerable distance with a reasonably short exposure. He stretched two platinum wires, whose diameter was $0^{mm}.040$, parallel to one another, and at a distance apart of 2^{mm}. Two prisms were placed near the middle of the wire, one opposite each wire, with their refracting angles turned in opposite directions. The two ends of the wire will thus be formed on the photographic plate by the rays which only traversed the air, while the central portion is formed by the rays which have traversed the prisms. The photographs were then mounted on a very accurate dividing engine, and examined for any displacement of the central part of the lines relatively to the two ends. In this way he was enabled to show that, for the transparent substances examined (glass, ebonite, aluminium, etc.), the index of refraction exceeds unity by less than .000001. For the more opaque substances, like Zn and Fe, the accuracy of the experiment is only about one-twentieth of the above. To obtain an idea of the possible wave-length, M. Gouy made use of a well-known diffraction experiment. A slit $0^{mm}.045$ in width was placed at a distance $2^{m}.5$ from a photographic plate on one side, and at an equal distance from the linear source of Röntgen rays on the other side. At a distance of $0^{mm}.055$ from the center of the resulting photograph of the diffraction slit the intensity is far less than one-fourth the maximum intensity. By calculating the wave-length of light which would give as rapid a falling off in intensity as this, he finds that it must be far less than 50.

This experiment, therefore, seems to show that the wave-length of these rays (if they are waves) must be less than $\frac{1}{100}$ that of ordinary green light.

L. Fomm (*Wied. Ann.*, No. 10, 1896), by a somewhat similar experiment with a diffraction slit, places the upper limit of the wave-length at 140. G. Sagnac (*C. R.*, **122,** No. 13) uses a wire grating and calculates from a scarcely measurable widening of the image of the slit an upper limit of 400.

Professor Thomson has, by the use of interference fringes, endeavored to detect any motion of the ether near an electric vibrator. As this motion would be oscillatory, and for an undamped vibrator the average velocity would be zero, he has used a heavily damped vibrator, hoping thus to obtain an average velocity which would be finite. The experiment gave a negative result. A similar experiment to detect any motion of the ether around a tube sending out Röntgen radiations was carried out, but failed to show any evidence of ether motion. A similar experiment has been made, independently, by Threlfall and Pollock (*Phil. Mag.*, December 1896) by an application of Michelson's interference experiments. They were unable to detect any shift of the interference bands when the Röntgen radiations were started and stopped. From the limit of accuracy imposed by the conditions of the experiment, they were led to the conclusion that Röntgen radiations are not associated with ether velocities exceeding 177^{m} per second, which is one thousand times less than the velocity of the cathode rays according to the measurements of Professor Thomson.

Among the most noteworthy properties of these rays are their power of rendering all bodies, dielectrics as well as conductors, conductors of electricity (J. J. Thomson and J. A. M'Clelland, *Proc. Phil. Soc. Cambridge*, Vol. IX, Pt. II). A gas which has been thrown into a conducting state by the passage of Röntgen rays, retains for a considerable time its power of discharging electrified bodies. This condition is destroyed if an electric current be passed through the gas. The gas while in this state behaves like a dilute solution of an electrolyte. When a current is sent through a gas which is being exposed to Röntgen radiation, the current destroys and the rays produce the structure which gives conductivity to the gas. When the rate of destruction is equal to the rate of production we have a saturation current, and any further increase in the E. M. F. can cause no further increase in the current. The conducting property which these rays

confer on gases is not destroyed when the gas is passed through metal tubes raised to red heat; it is, however, filtered out, as it were, by passage through water and glass wool. This latter, together with the comparatively slow migration velocity obtained for "ions" of a gas in this state conveying a current, has led Professor Thomson to think that the conducting structure is of a coarse nature, and that we are here perhaps dealing with aggregations of molecules rather than with the more simple ion used to explain electrolytic phenomena (J. J. Thomson and E. Rutherford, *Phil. Mag.*, No. 258). An experiment was made to determine if these rays were generated when the phosphorescence of the glass was produced by other means than the discharge from a negative electrode (Thomson, *Proc. Phil. Soc. Cambridge*, Vol. IX, Part II). For this purpose intense phosphorescence of the glass was produced by a ring discharge in an electrodeless bulb. In a second experiment this tube was filled with oxygen, which itself becomes phosphorescent, but in neither case was any effect observed on the photographic plate. It is, therefore, possible to have phosphorescence without the presence of Röntgen rays. Another experiment was carried out to see whether a negative electrode could produce these rays without the presence of the walls of the tube. For this purpose a piece of photographic plate was enclosed in a small ebonite box and placed inside the tube between the negative electrode and the wall of the tube, but in this case also no effect was produced on the photographic plate.

There is a general agreement among observers that the Röntgen rays discharge bodies, whether electrified positively or negatively; some, however, seem to have obtained evidence of an independent electrification due to the rays, without agreeing as to the sign of this electrification. Gerchun and Borgman find it negative, and Righi positive. Benoist and Hurmuzescu (*Jour. de Phys.*, **5**, pp. 358–362, 1896) have repeated the experiments with an improved form of electroscope, and also with an electrometer, but fail to find any evidence of such electrification. Lord Kelvin (*Nature*, December 31, 1896), by an experiment on air, unelectrified to begin with, finds that if such air be exposed to the Röntgen rays it shows decided negative electrification.

Benoist and Hurmuzescu find that the rate of discharge of electrified bodies depends not alone on the intensity of the radiation, but also on the nature of the charged surface. This is similar to the action of ultra-violet light, whose power of discharging bodies also depends

on the nature of the surface, but the order of the metals is not the same in the two cases. For the Röntgen rays the most opaque metals (Pt, Hg, etc.) come at the top of the series, *i. e.*, they are discharged most rapidly, while the metals which are discharged more slowly are the transparent ones like aluminium. From this arrangement of the metals they conclude that the power of the different metals for utilizing the energy of the rays for the dissipation of electricity varies inversely as their transparency. The theory of the pulverization of the metals has been used to explain the phenomena in the case of ultra-violet light, but this is scarcely applicable here, for similar effects were observed when the metals were imbedded in solid dielectric media, such as paraffine. In the investigation of the effect of the surrounding gas, they find that for the same gas at different pressures, or different gases at the same pressure, the rate of discharge is proportional to the square root of the density.

Another interesting property of the Röntgen rays has been pointed out by Aubel (*Jour. de Phys.*, **5**, November 1896) who has compared the diathermanous property of bodies and the transparency to these rays. He calls attention to the fact that the presence of the halogens and of sulphur in a molecule increase its diathermancy but renders it more opaque to the rays; while bodies containing the elements carbon, hydrogen, and oxygen allow the rays to pass readily, although they absorb strongly heat radiations. Comparatively thick layers of vapor, however, of such opaque substances as chloride of thallium seemed absolutely transparent.

Mr. C. T. Wilson, by studying the effect of Röntgen rays on cloudy condensation (*Proc. R. Soc.*, March 1896), finds that, while air exposed to the Röntgen rays requires to be expanded just as much as ordinary air in order that condensation may take place, these rays have the effect of greatly increasing the number of drops formed and the time during which the fog remains. In ordinary air the fog settles down in a few seconds, while in the air exposed to the rays it persists for some minutes.

Cajori (*Amer. Jour. Sci.*, **2**, 152), who exposed photographic plates, suitably protected from moisture and light, on the top of Pike's Peak, failed to detect any evidence of the Röntgen rays in solar radiation. Similar results have been obtained by Lea (*Amer. Jour. Sci.*, **1**, 363-364, 1896) and others.

Winkelmann and Straubel (*Wied. Ann.*, No. 10, 1896) found that

when the Röntgen rays strike upon a plate of fluor-spar and also upon glass containing certain of the rare earths, especially zirconium, they give rise to what they briefly call spar rays. They have studied the spectrum of the spar rays and find that it begins at $\lambda = 3960$, is a maximum at 2800, and ceases at 2330. By placing a piece of spar below the photographic plate they obtain effects many times stronger than if the Röntgen rays alone acted ; if a thin sheet of paper is slipped between the sensitive layer and the fluor-spar, its effect is cut off, thus showing that the Röntgen rays that struck upon the surface of the spar must have given rise to new waves, for, had the Röntgen rays been simply reflected, the paper would not have cut them off. Similar effects from phosphorescent sulphide of zinc, have been observed by Henry (*C. R.*, **122**, 312–313, 1896). Henry has also found that when a zinc sulphide screen, wrapped in carbon paper, is covered with the object to be examined and exposed to the radiation of a Crookes' tube for some minutes and then removed to a dark room, the image shines for at least one quarter of an hour, so that the smallest details of the image can be made out. The light emitted by glowworms was found to be capable of penetrating blackened paper and affecting a photographic plate.

Experiments by M'Clelland (*Proc. R. Soc.*, No. 360) and others seem to show that the Röntgen radiations from a vacuum bulb are not homogeneous. By measuring the relative transparency of some substance, *e. g.*, glass and tinfoil (by passing the rays through them and observing the rate at which conductors are discharged in the two cases), and then measuring the relative transparency of the same two specimens after the rays have passed through a few additional sheets of tinfoil, it was found different in the two cases. This can only be explained by assuming that the rays are not homogeneous, and some are more readily absorbed by the glass and others by the tinfoil.

In an article by T. C. Gilchrist (*Bull. of the Johns Hopkins Hospital*, 8, No. 71) the effect of the Röntgen rays on the skin and joints is fully discussed. Of the thousands of experiments that have been made with these rays only twenty-three are known to have been followed by injurious effects. In several of these cases the injurious effects have resulted from short exposures.

C. W. WAIDNER.

JOHNS HOPKINS UNIVERSITY,
February 25, 1897.

Uber die ultravioletten Funkenspectra der Elemente. Sitzungsberichte d. K. Akad. d. W. Wien. Bd. **105**, pp. 389–436, 503–574, 707–740, 1896. FRANZ EXNER und E. HASCHEK.

THESE three papers describe a series of measures on more than nineteen thousand ultra-violet lines in the spark spectra of the following eleven elements, viz., Ag, Cu, Mn, W, Mo, Pt, Pd, Ir, Rh, Ru, Os. The spectra were photographed in the ordinary way with a Rowland 5-foot concave grating. Practically all the measures lie between λ 4700 and λ 2100. The blue and violet of the first order spectrum were separated from the ultra-violet of the second order by placing a glass plate so as to cover one-half of the slit. On the part of the photographic plate affected by the uncovered portion of the slit, one has the lines of both orders; while the light which passes through the glass belongs to the first order.

One is naturally curious to learn in what manner the stupendous task of measuring nineteen thousand wave-lengths was approached. Nothing could be simpler. Several methods, we venture to think, might be more accurate. The spectrum to be measured, together with its comparison spectrum, Iron, was projected upon a screen, the image being thirty times larger than the original. On the screen is a half-centimeter scale; this scale is so adjusted that the reading of each of the Rowland standards is its correct wave-length. The unknown wave-lengths are thus interpolated and their values read directly from the scale. By this convenient method, the authors think they have determined their wave-lengths with an error not exceeding 0.1 Ångström unit. They compare their values for 132 Osmium lines with those of Rowland and Tatnall for the same lines, and find the average deviation 0.03 Angström unit. The results are, therefore, perhaps more accurate than one would imagine when he remembers that the physical width of the line, the grain of the plate, and (between standards) the distortion of the projection-lens, all cut a figure in this method. A series of wave-length determinations possessing this degree of accuracy (0.03 to 0.1 Angström unit) is of great value. It is the more to be regretted, therefore, that the values are given only to the first decimal place, in contravention to the usual practice of giving results to one place beyond where they are considered thoroughly trustworthy.

Accompanying the text, are beautiful photogravure reproductions

of nearly all the spectra studied. Each strip includes about 700 Ångström units, and is about seven inches long. The separation of the overlapping spectra of different orders is excellently shown on these plates. H. C.

COLOR-PHOTOGRAPHY.

1. *Presidential Address.* W. LECONTE STEVENS. *American Association for the Advancement of Science*, **44**, 45, 1895.
2. *Zur Photographie in naturähnlichen Farben.* P. GLAN. *Wied. Ann.*, **58**, 402.
3. *On a Method of Photography in Natural Colors.* J. JOLY. *Nature*, p. 91, November 28, 1895.
4. *On Color Photography by the Interferential Method.* G. LIPPMANN. *Proc. R. Soc.*, **60**, 10.
5. *Photography in Colors. Nature*, p. 318, February 4, 1897.
6. *Photographic Reproduction of Colors. Nature*, p. 422, March 11, 1897.

IN the first of these papers we find an account of the work on color-photography up to the year 1895. Of the various methods described, the one perfected by F. E. Ives (*Jour. Franklin Inst.* **125**–**135**) is the most satisfactory. He takes three negatives through three compound color-screens, each adjusted by experiment so as to transmit in the correct proportion all the colors that go to make up one of our primary color sensations. From each of these negatives he prints a positive and dyes the positive red, green, or blue-violet according to the color sensation corresponding to its negative. When such a set of positives are superimposed and viewed by transmitted light we see an exact likeness, in its natural colors, of the object photographed.

In the second paper Glan suggests that, instead of color screens, a direct vision spectroscope might be placed in front of the lens of the camera. Then by a suitable arrangement of diaphragms in the spectroscope we could photograph the object in any colored light desired. Since Ives has shown that we must employ screens of compound, and not of pure colors, I think his method is preferable to Glan's.

Joly's method is based upon the same principle as that of Ives, but he combines the three photographs in one. He takes his negative

through a screen ruled alternately with orange, green, and violet lines. From this he prints a positive, and views the positive through a similar screen ruled in red, green, and violet. When this screen is so adjusted that the red lines are over those parts covered in the negative by the orange lines of the taking screen, the green and violet will lie over the green and violet portions, and if the lines are close enough together, the photograph will appear colored. He rules 300 to 1000 lines to the inch.

Lippmann employs a transparent photographic film, which he backs with a layer of mercury. The light reflected from the mercury interferes with the incident light so as to form standing waves in the film. Under these conditions the reduced silver forms parallel layers whose distances apart at any point are equal to one-half the wave-length of the light incident there. Thus the film is converted into a kind of reflecting grating, and when viewed at the angle of specular reflection, appears colored.

The last paper describes the results of a process of color photography invented by M. Villedieu-Chassagne. He washes an ordinary photographic plate in a colorless solution, takes a negative upon it, and from this he prints a positive upon a similarly prepared plate. Neither negative nor positive is colored, but the positive has the power of absorbing certain dyes in the correct proportions to give the natural colors of the object photographed. The natures of the solution and dyes have not yet been made public.

During an address before the Society of Arts, Sir Henry Trueman Wood exhibited some transparencies taken by a secret process devised by Mr. Bennetto, of Newquay, in Cornwall. They are described as "much clearer than those obtained by the Chassagne process, and look almost like water color sketches." "The colors are imprinted on the plate just as are the light and shade in an ordinary monochrome photograph, and are directly visible to the eye, without any subsidiary apparatus."

N. E. Dorsey.

Johns Hopkins University,
March 11, 1897.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

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NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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PLATE XIX.

S

P  F

VENUS.

1889, MAY, 29^{d} 11^{h} 12^{m} A.M.

12 inch Equatorial. E. E. Barnard.

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME V MAY 1897 NUMBER 5

PHYSICAL AND MICROMETRICAL OBSERVATIONS OF THE PLANET VENUS, MADE AT THE LICK OBSERVATORY WITH THE 12-INCH AND 36-INCH REFRACTORS.

By E. E. Barnard.

No other object has caused more controversy and produced more varied testimony in the determination of its rotation period than the planet Venus. This rotation controversy has raged for upwards of two centuries, with fitful periods of quiescence — after some observer more combative than the rest had definitely "settled the question" — only to break out again with renewed virulence when a new champion for rotational honors entered the field.

The periods assigned to the planet vary all the way from twenty-three or twenty-four hours to 225 days. One of the short-period men has gone so far as to produce a period, derived from drawings made a few days apart, with a decimal running into the ten-thousandth of a second, which ought certainly to be convincing enough, as a smaller subdivison of time would be an insensible quantity and ought never to be stickled for in determining the duration of a planetary day.

These discrepancies are due in the main to the difficulty — from various causes — of seeing the markings which really exist on the surface of Venus.

Certainly the prime factor in observations of the surface features of this planet, is a steady atmosphere. Without this one can hope to do little or nothing at all with Venus, no matter how perfect his telescope. When we take into account also that the observations must be made in the daytime to get as high an altitude as possible, we find the difficulty is further augmented, for in the day the atmosphere is never so steady as it often is at night. Take into account, further, that the markings on this planet are exceedingly delicate, with but little contrast, and we have — considering the promise its great brilliancy holds out — perhaps one of the most disappointing objects in the entire heavens.

Venus was frequently observed with the 12-inch refractor at Mt. Hamilton during the years 1888–95, but I never could (with but one exception) satisfactorily see the markings. Vague, indefinite spots were often visible, but it was not possible to see them well enough to identify them for rotational purposes.

The atmospheric conditions at Mt. Hamilton were seldom at all favorable for day observations. The heating of the southern, contrasted with the cooler northern slopes, produced an unsteadiness of the air which was almost always present in the daytime.

There were times, however, when the air was thick with smoke and dust, when the seeing was fairly good. But this condition, though it tended to produce steadiness, was sometimes accompanied with excessively bad seeing, so that it could not always be depended upon as a criterion. A clear blue, transparent atmosphere almost always proved unsteady, and this seemed to hold at night also. Indeed, so marked was this peculiarity that one was wont to say when the sky was a rich dark blue in the day that the night would be bad, so that a dark-blue sky really became synonymous with poor seeing.

The 29th of May, 1889, was remarkable for the thickness of the atmosphere from smoke and dust. One could scarcely see across the cañon so dense was the haze. Examining Venus with the 12-inch on this date I was struck with the remarkably

perfect definition. There was not the slightest tremor of the image. The markings on the surface of the planet were distinctly seen, though they were difficult and very delicate. A careful drawing was made of these details, which were distinct enough to be drawn with perfect satisfaction. This perfection of definition did not last long enough to show any motion in the spots—the ordinary day-seeing soon taking its place.

Venus was looked at at this time with the 36-inch, but the seeing with the great instrument was not perfect enough to show the markings satisfactorily. Indeed, in all subsequent observations of Venus the 12-inch was preferable.

This drawing is herewith presented, and I am satisfied the markings shown exist on Venus and are here closely represented. From their position on the disk it will be seen that they are large broad spots, for they must be greatly foreshortened in their position near the limb.

The circumstances under which this drawing was made are memorable with me, for I never afterwards had such perfect conditions to observe Venus. A close lookout was kept on the planet in hopes of again seeing the spots, but if seen again they were too poorly defined to be recognized. On several dates thereafter when the seeing was fair, the same region seemed to be visible; especially on June 10, 1889, did I have the impression that these markings were present, but the details could not be made out, and probably the three spots were blended into one long vague spot from the lack of definition. On several other dates I seemed to see the same thing, especially on the forenoon of June 12, when a sketch showed about the same appearance.

The planet was watched through many years, but indifferent seeing always baffled one and no satisfaction could be gotten out of it.[1]

In these observations of Venus I have tried various methods to improve the image, such as contracting the aperture of the

[1] On a number of occasions, with both telescopes, I tried to see the dark part of Venus by occulting the bright part, but without success.

object-glass; using a small diaphragm over the eyepiece; using colored glasses, etc. Of these the best results were got by contracting the aperture between the eye and the eye lens of the eyepiece.

I also found it a very great advantage to cover the head and the eye end of the telescope with a large dark cloth to cut out all extraneous light; one has no idea how much this simple method aids in observing a difficult object, either in the daytime or at night, but especially in the day when observing Venus.

In 1895, in conformity with my plan to measure the diameters of all the planets with the 36-inch, I secured a series of measures of the diameter of Venus during the months of May, June, and July, when the planet was approaching inferior conjunction. The customary west wind that springs up nearly every evening during the summer months interfered very much with the observations, often making it impossible to secure measures.

These measures were made with the full aperture of the object-glass except on one date, when it was reduced to twelve inches. A small cap over the eyepiece (next the eye) with a hole in it about $0^{in}.04$ diameter was always used, however. This was very useful in sharpening the image and reducing the glare.

Two magnifying powers were used, 350 and 520. The smaller of these was generally preferred, as the measures were less affected by the oscillation of the image due to wind.

No recognizable markings were seen on the planet during these measures nor at other observations with the 36-inch, though vague suggestions of spots were frequently present.

The measures are of that diameter essentially perpendicular to the orbit of Venus. They are corrected for refraction and in next to the last column are reduced to distance unity (1). There does not seem to be any decided systematic difference in the measures due to magnifying power. One or two measures are rather largely discordant, but these can be attributed

to the conditions of observation—shaking of the telescope by the wind or poor definition. No illumination of the wires was necessary and the method of double distance was employed.

In the second column of the following table the standard Pacific times of sunset are given. It will be seen that the measures were made about sunset—some before and some after. It was not possible to measure the planet much after sunset because of the increased disturbance of the image and from the fact that it soon got beyond the reach of the great telescope.

MEASURES OF THE DIAMETER OF VENUS IN 1895.

S. P. T.	Sunset	Mag. power	Seeing	Observed	Δ 1	Resid.
May 6^d 7^h 6^m	6^h 59^m	350	4	14″.43	17″.30	+ 0″.10
" 6 7 16	....	520	3	14 .61	17 .51	— 0 .11
" 12 7 30	7 4	520	3	14 .99	17 .35	+ 0 .05
" 13 6 56	7 5	520	3	15 .04	17 .30	+ 0 .10
" 13 7 3	....	350	3	14 .83	17 .06	+ 0 .34
June 2 6 54	7 20	520	2–3	17 .16	17 .23	+ 0 .17
" 2 7 2	....	350	2–3	17 .19	17 .25	+ 0 .15
" 3 7 20	7 20	350	3	17 .52	17 .45	— 0 .05
" 9 6 48	7 24	350	3	18 .44	17 .51	— 0 .11
" 9 6 58	....	520	3	18 .27	17 .35	+ 0 .05
" 10 7 58	7 25	350	2	19 .26	18 .13	— 0 .73
" 16 6 17	7 27	350	3	19 .36	17 .32	+ 0 .08
" 16 6 20	....	520	2	19 .35	17 .31	+ 0 .09
" 17 7 5	7 27	350	2	19 99	17 .73	— 0 .33
" 17 7 10	....	520	2	20 .10	17 .83	— 0 .43
" 24 7 25	7 29	350	4	20 .59	17 .10	+ 0 .30
" 30 6 25	7 29	350	3	22 .23	17 .39	+ 0 .01
" 30 6 30	....	520	3	22 .33	17 .47	— 0 .07
July 1 7 23	7 29	350	4	22 .33	17 .28	+ 0 .12
" 1 7 29	....	520	3	22 .65	17 .53	— 0 .13
" 7 7 55	7 28	350	3–4	24 .38	17 .67	— 0 .27
" 8 7 27	7 28	350	2–3	24 .03	17 .23	+ 0 .17
" 14 7 10	7 26	350	3–4	25 .57	17 .09	+ 0 .31
" 14 7 18	....	520	3–4	25 .63	17 .13	+ 0 .27
Mean..........					17″.397	

The mean of these measures reduced to distance unity gives 17″.397 for the diameter of Venus, which corresponds to an actual diameter of 7826 miles.

NOTES ON THE MEASURES.

1895, May	6.	Planet clearly defined. No spots seen. Measures good.
"	6.	Image unsteady. Seeing getting bad.
"	12.	Very heavy wind shaking telescope. Image oscillating badly.
"	13.	Measures very good.
1895, May	13.	Not a tremor of the image from wind or vibration of the telescope.
June	9.	Image jumping and fluttery.
"	10.	Wind shaking telescope.
"	16.	High northwest wind, but not striking telescope.
"	24.	Wind shaking telescope too much to use higher power.
"	30.	Wind shaking telescope.
July	1.	No wind.
"	14.	Slight wind shaking telescope. Aperture reduced to twelve inches No definite markings.

In *A. N.*, 3204, Bd. 134, Dr. L. Ambronn gives his measures of the diameter of Venus, made during 1892, with the great heliometer at Göttingen. I am indebted to his paper for the following list of previous measures of the diameter of Venus, including his own measures in 1892.

These measures will be interesting in comparison with those made with the 36-inch.

(1) E. Hartwig, Breslau heliometer	17".67
(2) E. Hartwig's reduction of the Oxford measures	17 .582
(3) E. Hartwig, from double-image observations by Kaiser	17 .409
(4) E. Hartwig, nine measures in Bahia-Blanca	17 .406
(5) B. Peter, two measures in Bahia-Blanca	17 .216
(6) F. Küstner, two measures in Punta Arenas	17 .312
(7) A. Auwers, measures during transit	16 .801
(8) L. Ambronn, Göttingen heliometer	17 .711
Mean	17".389

It will be seen that these are in very close agreement with my measures with the 36-inch in 1895.

Yerkes Observatory,
April 1897.

NOTES ON THE DETERMINATION OF THE FOCUS OF AN OBJECTIVE.

By H. C. Lord.

In photographing stellar spectra with the compound star spectroscope, it is of the utmost importance that the slit be placed accurately in the focal plane of the great objective, for the particular part of the spectrum to be examined. This is especially true when the so-called achromatic objective is corrected for the visual portion of the spectrum. As I have been unable to find any published directions as to the proper method of accomplishing this result, which were at the same time specific and accurate, or any experiments which would show the precision to be expected, I have thought that my experience with different methods tried and the results obtained might not be without interest to the readers of the Astrophysical Journal.

The instruments used were the twelve and one-half inch equatorial and large star spectroscope of the Emerson McMillin Observatory, which are fully described in the Astrophysical Journal, 4, 1. The battery of two prisms was used in every case. A less dispersion might have been better, but I was anxious to use the instrument under the same conditions as those in which it was to be used for regular work.

The first method tried was that due to Professor Young and described in the *American Journal of Science*, No. CXIV, namely, of placing the limb of the Sun over one-half the slit and focusing until the line of division of the bright and faint spectra appeared sharp. The seeing was never good enough for this method to give even an approximate place. The same method was tried, using the Moon in place of the Sun. The results were much more accurate, but on account of the faintness of the lunar spectrum it was difficult to accurately focus the observing telescope. The following plan was then tried: The reading of the scale on the draw-tube of the observing telescope,

when $H\beta$ was in focus, the line used in all my experiments, was determined from a number of pointings on the Sun. These were made at widely differing temperatures and the setting found to be constant within $0^{mm}.1$. At night, with a small electric lamp placed in front of the slit so as to show a continuous spectrum and the prisms so placed that $H\beta$ was under the cross wires and the observing telescope set at the proper scale reading, the eyepiece was focused on the cross wire, which appeared dark on a colored field. The telescope was then turned upon a star and the whole collimator racked in and out until the spectrum appeared linear where it was crossed by the cross wire. Five pointings were made, the eyepiece being focused between each pointing. Temperatures were read from two thermometers graduated to $\frac{1}{2}°$ F., placed one near the objective and one on the spectroscope, the mean of the two being taken as the temperature. In this manner fairly accordant results were obtained at first. The results are given in the table below together with the focus computed by a formula whose derivation will be described later. After October 10 my eye had a long rest until November 6, when a focus for 50° F. was found which was higher than that previously found for 62° F. Similar results were obtained on November 9. I attributed this to the inability of the observer to prevent his eye accommodating itself to slight changes in focus.

This method was then abandoned and the following photographic method was adopted. The scale reading of the camera for the $H\beta$ focus was determined as before from the Sun, both photographically and by means of a small eyepiece slide which takes the place of the plate holder. Both methods gave the same result. The slit of the spectroscope was then set parallel to an hour circle, in order to have the resulting photograph as narrow as possible, the telescope turned on Polaris and a series of from five to seven exposures given with the collimator set at a different point for each. These points differ by $0^{mm}.5$ in all except those made on November 30, which differed by a single millimeter. Temperatures were read from two ther-

mometers placed as before, readings being taken at the end of each exposure. The average of all was taken as the temperature. At the end of the exposure the artificial $H\beta$ was photographed on the plate. The distance from the $H\beta$ line to the point on the spectrum where it was narrowest was then measured. This could not be told closer than the nearest millimeter, though the results were read to the nearest fifth millimeter. In selecting this point the eye is guided by three factors. The spectrum should be the narrowest, the edges the sharpest, and bearing in mind the color sensitiveness of the plate used, the density should be the greatest. Let this measured distance be d, s the scale reading at which the negative was made, s_0 the scale reading for the given temperature when $H\beta$ is in focus, m s a constant depending upon the slope of the color curve at that point; then evidently $s = s_0 + dm$. d and s are given by observation. Each plate gives one equation and from these equations the values of s_0 and m were calculated by the method of least squares. Each series of plates were measured on three different days.

This method has proved entirely satisfactory, and the results are given in the following table. The 4th, 5th, and 6th columns give the focus determined from any set of plates on each of the three days that it was measured. The 7th gives the means of I, II, and III. From these means the temperature equation $s_0 = 20^{mm}.6 + 0^{mm}.037\ (T^\circ - 0^\circ)$ was computed by the method of least squares. The 7th column gives the value of s_0 computed from the formula for the given temperature. The columns 10, 11, and 12 give the values of m. Column 14 gives the temperature at which the visual observations were made, 15 the observed focus, 16 the focus computed from the preceding formula. This table brings out several facts: (1) That the eye tends to give a constant error in the position of the focus amounting to nearly 1^{mm}, a quantity too large to be neglected. (2) It shows that the photographic method gives much more accordant results than the visual method. (3) The constancy of the value of m, taken in connection with the close agreement of the results for the focus, will tend to show that the accuracy reached is real

PHOTOGRAPHIC.

Date	No. plates	Temp. F.	Focus for $H\beta$ I	II	III	Mean	Comp. focus	C—O	M I	II	III
1897—January 25...	6	— 5 .5	$20^{mm}.3$	$20^{mm}.5$	$20^{mm}.2$	$20^{mm}.3$	$20^{mm}.4$	$+0^{mm}.1$	—0.31	—0.35	—0.32
1897—*February 26.	6	+16 .6	20 .9	20 .8	20 .9	20 .9	21 .2	+0 .3	—0.31	—0.31	—0.37
1897—*February 27.	5	+17 .7	21 .4	21 .4	21 .5	21 .4	21 .3	0 .1	—0.30	—0.32	—0.36
1896—November 30.	5	+17 .8	21 .4	21 .1	21 .3	21 .3	21 .3	+0 .0	0.37	—0.33	0.33
1897—February 27..	5	+18 .0	21 .6	21 .8	21 .5	21 .6	21 .3	0 .3	0.31	—0.37	—0.32
1896—December 1..	5	+18 .5	21 .4	21 .4	21 .5	21 .4	21 .3	0 .1	—0.38	—0.25	—0.29
1897—February 27..	5	+19 .0	21 .4	21 .4	21 .1	21 .3	21 .3	+0 .0	—0.35	—0.32	—0.35
1896—December 3..	5	+24 .5	21 .7	21 .4	21 .7	21 .6	21 .5	0 .1	—0.27	—0.40	0.35
1897—*February 24	6	+30 .5	21 .4	21 .4	21 .7	21 .5	21 .7	+0 .2	—0.34	—0.22	—0.34
1897—March 7.....	5	+34 .5	21 .9	21 .8	21 .7	21 .8	21 .9	+0 .1	—0.31	—0.32	—0.30
1896—December 5..	6	+42 .0	22 .4	22 .0	22 .0	22 .1	22 .2	+0 .1	—0.44	—0.37	—0.39
1896—December 9..	7	+44 .0	22 .4	22 .1	22 .4	22 .3	22 .2	0 .1	—0.27	—0.34	—0.34

*On these dates camera set $0^{mm}.1$ wrong.

NOTE.—On February 27 three sets of negatives were made.

and not simply an accident of observing. It should be stated that though during this set of observations the spectroscope was frequently removed from the telescope, the system of stops provided on the instrument kept the distance, spectroscope to objective, constant.

VISUAL.

Date	Temp. F.	Obs. focus	Comp. focus	C—O
1896—September 1	62°.0	21mm.4	22mm.9	+1mm.5
1896—September 4	63 .2	22 .2	22 .9	+0 .7
1896—September 9	72 .7	22 .5	23 .3	+0 .8
1896—September 19	51 .8	21 .1	22 .5	+1 .4
1896—September 22	46 .0	20 .5	22 .3	+1 .8
1896—September 25	65 .2	22 .0	23 .0	+1 .0
1896—September 26	70 .3	22 .2	23 .2	+1 .0
1896—October 3	51 .8	21 .7	22 .5	+0 .8
1896—October 4	55 .0	21 .4	22 .6	+1 .2
1896—October 8	47 .4	21 .3	22 .4	+1 .1
1896—October 9	49 .0	21 .2	22 .4	+1 .2
1896—October 10	52 .2	21 .1	22 .5	+1 .4
1896—November 6	49 .8	22 .0	22 .4	+0 .4
1896—November 9	33 .6	21 .2	21 .8	+0 .6
1896—November 9	33 .9	21 .4	21 .9	+0 .5

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

III. THE INSTRUMENT AND OPTICAL SHOPS, AND THE POWER HOUSE.[1]

By George E. Hale.

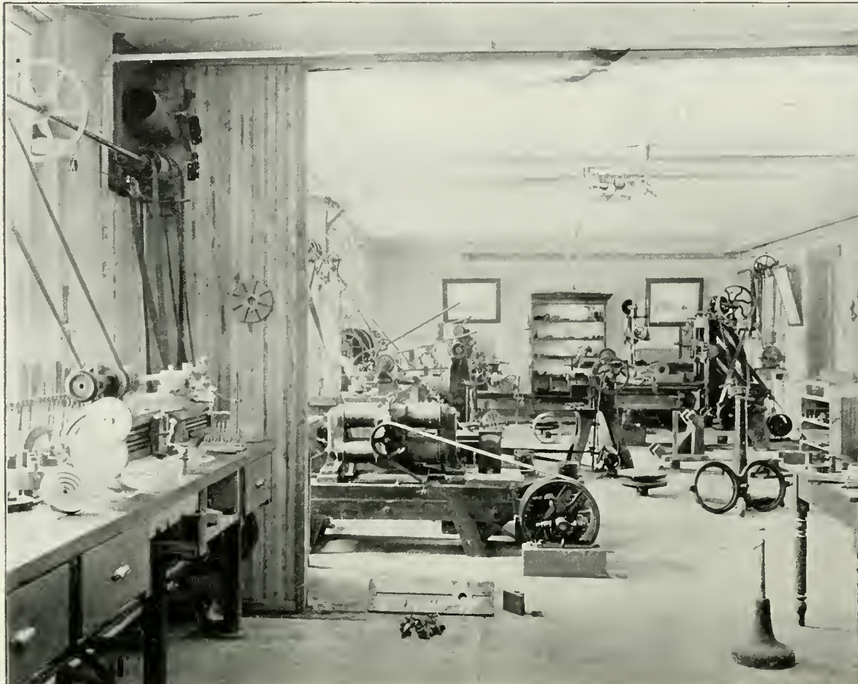
THE INSTRUMENT SHOP.

Many of the problems which confront the modern astronomer and astrophysicist require for their solution the invention of new methods of research and the construction of instruments of special design. This is particularly true in astrophysical work, and an observatory in which such investigations are to be carried on must be prepared to supply the needed apparatus. Fortunately for the progress of science in the United States, the instruments manufactured by the best firms in this country are not surpassed, if they are equaled, by those made abroad. As this is true of both the optical and mechanical parts, it is evident that no institution having the necessary funds at its disposal need have any difficulty in procuring the apparatus it requires.

The writer had found at the Kenwood Observatory, however, that while the principal instruments could be most advantageously obtained from Brashear and Warner & Swasey, it was necessary to have a workshop in which a skilled mechanician was almost constantly employed in constructing the numerous pieces of apparatus required in the solar and spectroscopic work. Those who have devised new instruments of research know only too well that it is frequently necessary to completely rebuild a piece of apparatus, or at least to make extensive alterations in it, before the expected results can be obtained. If an instrument is built under the eye of its designer, the ideas which may suggest themselves during its construction can be embodied in it at a minimum of cost. In fact, the very opportunity to see

[1] For previous articles in this series see the March and April numbers of this Journal.

PLATE XX.



INSTRUMENT SHOP OF THE YERKES OBSERVATORY.

each part made is not to be undervalued, for one not only obtains in this way a very intimate acquaintance with every detail, but is also much more likely to find important improvements suggesting themselves, which can be at once realized. For much experimental work it is also quite unnecessary to go to the expense of purchasing a finished piece of apparatus, when something answering equally well can be put together under one's own direction in a very short time. Another great advantage of having an instrument shop is the fact that repairs can be made at the moment they are needed, so that an important investigation need not suffer unduly from the results of an accident.

It seemed evident that if an instrument shop had proved to be indispensable at so small an institution as the Kenwood Observatory, it would be necessary to provide the Yerkes Observatory with the very best facilities for mechanical work. The machine tools which had been used for some years at Chicago were an engine-lathe, a shaper, and a small speed lathe. Subsequently there had been added an 8-inch Rivett "Precision" lathe and a Brown & Sharpe universal milling machine. These, with a large number of hand tools for wood and metal working, were available for the purposes of the Yerkes Observatory. It was decided to add to them at once a planer and a drill press, together with a circular saw and speed lathes for pattern work.

It had at first been planned to have the workshop in the power-house, but after it had been found that for various reasons this could not be done, rooms on the lower floor of the Observatory building were selected for the purpose. Professor Wadsworth, who had been placed in charge of the work of designing and constructing instruments, laid out the plan of the shop. A room 18×54 feet, occupying the southeast quarter of the ground floor,[1] was devoted to the metal-working tools, and smaller rooms, in the hall adjoining this on the east, were fitted up as pattern shop and forge room. To lessen the effects of vibration of the machinery, the cement floors of the shop are

[1] See Plate XI in the April number of this JOURNAL.

separated from the walls by strips of soft wood. For the same reason the main shaft, which runs the entire length of the large room, and extends through the partition into the pattern shop, is not hung from the ceiling, but supported from the floor. The countershafts, also, are mounted on floor supports, no shafting of any kind being attached to the ceiling. The results of this plan are very satisfactory, and up to the present time no traces of vibration have been detected, although sensitive instruments have been used in various parts of the building.

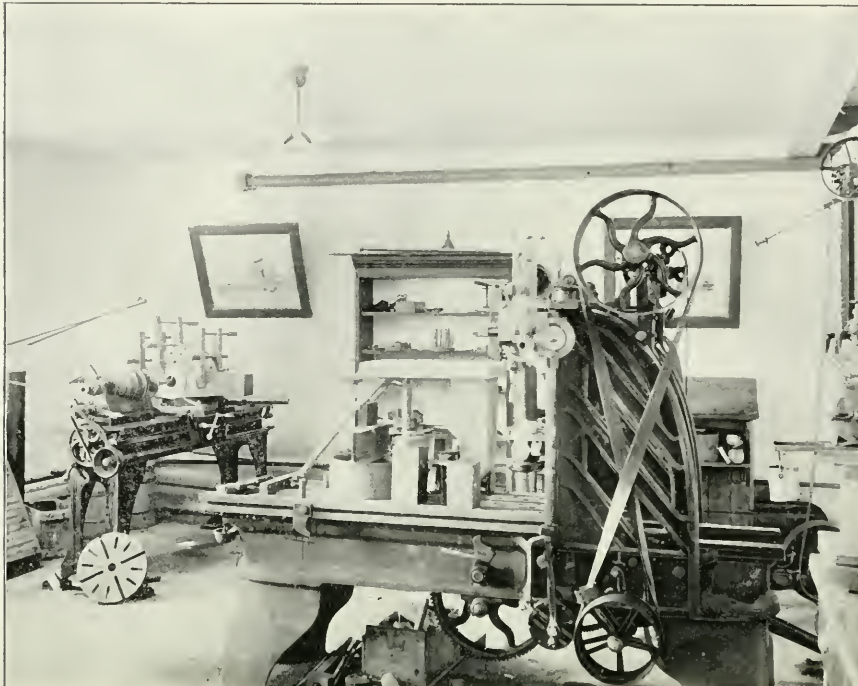
As the photographs show (Plates XX and XXI), the heavier machinery, consisting of a 16-inch Blaisdell engine lathe, Prentice drill press, 20 × 20 Wheeler planer, Brown & Sharpe universal milling machine, and shaper, have been grouped in the west half of the large shop. In this part of the shop there are also an emery grinder, speed lathe, bench for filing and chipping, and soldering bench. The motor which furnishes the power is a transformed 70-light Weston dynamo formerly used by the writer at the Kenwood Observatory to generate the current employed in his studies of the spectrum of the electric arc. But few alterations were required to adapt it to its present purpose, for which it serves very well.

The more delicate instrument work is done at the east end of the shop in a room separated from the space just described by a glass partition.[1] A filing bench runs the entire length of the south wall of this room, and is carried around on to the east wall. Upon this bench is mounted an 8-inch Rivett "Precision" lathe fitted with grinding attachment, Horton chuck, step chuck, and a set of split chucks. The change gears permit threads to be cut on both the English and metric systems. The shop is provided with a good collection of small tools.

The machine tools in the pattern shop consist of a circular saw with iron tilting table, and a large face-plate lathe of nine feet swing designed for pattern work and built by our own mechanicians. There is also a cabinetmaker's bench and a good assortment of wood tools. The adjoining forge room

[1] Not completed when the photograph reproduced in Plate XX was taken.

PLATE XXI.



INSTRUMENT SHOP OF THE YERKES OBSERVATORY.

contains a forge with hand blower, and a blacksmith's anvil with the necessary small tools.

The shops have been fitted up during the past winter by Professor Wadsworth and the two mechanicians. Although this has necessarily taken up much time, opportunity has nevertheless been found for other work. Among the machines and instruments constructed may be mentioned the 9-foot pattern lathe, planer chuck, large spectroscope,[1] rotating shutter for solar photography, set of universal clamps and supports for the laboratories, and an alt-azimuth mounting for a 24-inch reflector.[2] The 12-inch telescope of the Kenwood Observatory has been remodeled to adapt it to the higher latitude and different conditions of work of the Yerkes Observatory. The large spectroheliograph has also been partly rebuilt, and a grinding machine for the optical shop is now in process of construction. In addition to this much repair work has been done.

Two skilled mechanicians are employed in the shop. A recent gift from a friend of science in Chicago for the express purpose of constructing a machine for ruling gratings, designed by Professor Wadsworth, will now render possible the employment of a third mechanician, whose entire time will be devoted to this work. An interferometer will be required in perfecting the adjustments of the ruling machine. This will be constructed first in order that it may also be employed in Professor Wadsworth's determinations of the absolute wave-lengths of lines in the infra-red spectra of the elements. In addition to the ruling machine the most important instrument now being built in the shop is a 24-inch heliostat, castings for which are shown on the engine lathe and planer in Plate XXI.

THE OPTICAL SHOP.

According to a well-known saying, a reflecting telescope can be successfully used only by its maker. While this is of course not strictly true, the history of the larger reflectors has been

[1] Shown in Plate XVII in the April number of this JOURNAL.

[2] Shown in Plate XV in the April number of this JOURNAL.

such as to emphasize the meaning which it is intended to convey. No one can appreciate so well as the maker the peculiar sensitiveness of specula, and no one is so well prepared to overcome the difficulties encountered in their use. As the light-grasping power of specula depends upon the condition of the reflecting surface, it is of great importance that the silver film be kept highly polished, and that it be replaced by fresh silver when necessary. Recognizing from the outset the superiority of reflectors for stellar spectroscopic work,[1] the writer has always planned that the Yerkes Observatory should be provided with a large reflecting telescope as soon as circumstances would permit. It was thought best to secure the services of an optician to grind and polish the mirror at the Observatory, and subsequently to keep it in good condition. There was much other work for an optician to do, and it will be gathered from what follows that this plan of supplying our own needs, so far as it can be done to advantage, has not proved unprofitable.

Mr. G. Willis Ritchey, at one time assistant in the Cincinnati Observatory and later in charge of the woodworking department of the Chicago Manual Training School, was engaged in the spring of 1896 as optician. For many years Mr. Ritchey had carried on optical work as an amateur, and at the time of his appointment he had completed an excellent speculum of twenty-four inches aperture and only eight feet focus.[2] A 24-inch speculum of the same focal length as the Yerkes telescope (61 feet) now used in the writer's bolometric work, was made by Mr. Ritchey in a few weeks. This mirror well illustrates one of the most important advantages of the optical shop. For obvious reasons a professional optician frequently objects to sending out work which he regards as in any sense incomplete. As a bolometer one-sixth of an inch wide was to be used at the focus of this mirror, it is evident that it was wholly unnecessary to go to the expense of parabolizing. The desired spherical

[1] See a paper "On the Comparative Value of Refracting and Reflecting Telescopes for Astrophysical Investigations," this JOURNAL, 5, 119, 1897.

[2] Now temporarily used on an alt-azimuth mounting in the heliostat room.

figure was obtained in a very short time, and the total cost was only a small fraction of the regular optician's price for a finished parabolic mirror of the same dimensions. Later, if it is desired to use the mirror for other purposes, the parabolic figure can easily be obtained.

Almost the entire work of fitting up the unfinished north room (20 × 70 feet) which was chosen for the optical shop, has been done by Mr. Ritchey. Two rooms were partitioned off for the grinding machines. The larger of the two (20 × 21 feet) is to contain a machine designed by Mr. Ritchey for grinding and figuring a 60-inch glass disk. This large grinding machine is designed so as to allow the mirror, which lies horizontally during the grinding and polishing, to be quickly inclined to a nearly vertical position when it is to be tested. Two cranks, with adjustable throw or stroke, are used to give the desired motion to the grinding and polishing tools, the mirror, as usual, revolving slowly beneath these tools. The arms which communicate the motion of the cranks to the tools, can be lengthened or shortened while the machine is in motion, thus allowing changes in the position of the tools upon the glass to be made with ease and smoothness. One of these arms also carries the mechanism which rigorously controls the slow rotation of the grinding and polishing tools; and the same arm carries a lever for counterpoising a part of the weight of the tools during the process of grinding and polishing. Since the large disk of glass for the 60-inch mirror weighs nearly a ton, and the grinding tools several hundred pounds each, a strong lever, properly mounted and counterpoised, is necessary for lifting the glass and tools on and off the machine. The metal parts of this machine are being made in the instrument shop, and the heavy wooden frame is to be built by Mr. Ritchey.

The smaller room, 12 × 20 feet, contains the grinding machine used in making the two 24-inch mirrors already referred to. Mr. Ritchey will soon make on this machine a 24-inch flat mirror for the new heliostat. A line shaft running near the floor under a long bench by the windows is driven by an electric

motor. The grinding machines are connected with this shaft by means of a set of friction disks, so arranged that the speed of the machines can be varied through a wide range by the simple motion of a lever. Thus a variation of from 6 to 60 strokes of the tool per minute can be obtained while running.

The optical shop was prepared for use by covering the brick walls with two thicknesses of heavy building paper, separated from the wall and from each other by wood strips, thus leaving two air spaces. The lapped joints of the paper were firmly fastened with outside wood strips, and the whole was varnished. As a further means of maintaining the temperature constant, and of excluding dust, the windows of the grinding rooms are provided with a second inner sash, built in practically air tight. The line shaft is carefully boxed in, and the cement floor is painted. Both grinding rooms have doors in their west walls, which are opened when mirrors are to be tested by Foucault's method. By opening doors in the adjoining halls, a space 175 feet long becomes available for testing purposes. The room next the smaller grinding room contains the electric motor, and is fitted up with table and sink for silvering, the preparation of pitch tools and similar work.

A disk of glass 60 inches in diameter and 8 inches thick is expected to arrive shortly from the plate-glass works of St. Gobain, France. As soon as the large grinding machine is finished, this will be made into the large speculum for stellar spectroscopic work referred to above.

THE POWER HOUSE.

Power is needed in the Yerkes Observatory for many purposes. The motions of the 40-inch telescope are produced by five different electric motors, and the rising-floor and 90-foot dome are operated by two motors of greater horse-power. As has been stated, the instrument and optical shops receive their power from electric motors and the entire building is lighted by incandescent lamps. In order to furnish suitable means of generating power at a distance from the Observatory, Mr. Yerkes

has provided a separate brick building (Plate XXII) for the power and heating plant. The equipment of this building, all of which was generously presented to the Observatory by Mr. Yerkes, consists of two 8×10 Ideal engines, each carrying a direct-connected Siemens & Halske dynamo, with a capacity of 200 amperes at 125 volts. The switchboard is so arranged that either dynamo can be used to furnish both power and light while the other is idle. Steam is supplied by two 14×48 tubular boilers, equipped with Gulickson smokeless furnaces and grates. A duplex feed pump, connected with a feed-water heater and oil separator, furnishes the boilers with water. A well under the power-house, 165 feet deep, fed by springs, insures a constant water supply. From it a deep-well pump forces the water to three large receiving tanks in the Observatory building. The further equipment of the power-house includes automatic appliances for the control of steam and water, so arranged that the engineer can tell at a glance the condition of the entire system.

The chimney of the power-house is about 750 feet from the center of the large dome, in a direction (north of east) from which the wind very rarely blows. Up to the present time the small amount of smoke emitted by it has not given the slightest inconvenience. In case it should do so the efficient smoke consumers attached to the boilers could be brought into service. It has been found that they will almost instantly reduce a heavy cloud of black smoke to a hardly visible vapor.

The steam-pipes for heating, electric cables for power and light, and the water pipes are led underground from the power-house to the Observatory. Mr. E. N. Myers is the engineer in charge of the heating and power plant.

YERKES OBSERVATORY,
April 1897.

(*To be continued.*)

AUTOMATIC PHOTOGRAPHY OF THE CORONA.

By David P. Todd.

The great variety of problems arising in the photography of the corona and its spectrum, and yet unsolved, led to the equipment of the Amherst Eclipse Expedition to Japan last year with a type of apparatus essentially novel. The uncertainty of clear August skies in the Hokkaido also contributed to this decision; for should totality be cloudy, as unfortunately proved to be the case, the expedition might still bring back results of much significance in further eclipse work, provided the practicability of operating a large number of photographic instruments as an automaton could be demonstrated.

My attention was first called to this subject in 1878, on the return of the government expeditions to Washington. Excellent photographs had been obtained; but the number of instruments available for a manual routine and the number of photographs obtainable by hand-exposure struck me as exceedingly meager for an occasion when, like a total eclipse of the Sun, the money value of a single second is often hundreds of dollars. And this would still be true even if the human mechanism remained unperturbed under the strain and tension of totality; but sad experience shows its frailty, as attested by numerous and unfortunate instances of slips in the execution of a perfectly arranged programme, no matter how constantly rehearsed.

Then, too, the few exposures with any given instrument ordinarily precludes the chance of experimenting in the development of the negative. If a single series of exposures is obtained, representing a complete range in time, and one of these is developed too far, it is extremely desirable to have at hand an exact duplicate as to instrument and exposure; for the error of judgment may then be corrected. Also the detailed study of characteristic coronal forms has so far been greatly

hampered by the lack of sufficiently large numbers of original negatives for distribution among prominent students of solar physics; even the best transfer from a negative of the corona rarely shows everything that the original does. Our only present available method is to secure originals in sufficient abundance for extended distribution. This demands a great reduction of the time ordinarily lost in changing plates by hand; and the work of our expedition has proved, notwithstanding the clouds, that all the conditions can be amply met by the ease, precision and certainty of well-devised and carefully constructed mechanical movements.

Besides all this there is a wide range of questions not yet solved, for the testimony of past eclipses is by no means uniform: whether small instruments may not be equally effective with large ones; whether reflectors are superior to refractors; the proper sort of instrument to depict the faint outlying streamers, and the more important question of exposure suitable for them: whether the wet process may not be superior to the dry; whether orthochromatic screens should be used, and of what shade; how may the very bright inner and the excessively faint outer coronas be photographed on a single plate; and so on. Naturally we get some light on these questions from exposures upon the Moon and other objects, but the conditions of an eclipse are so divergent from the ordinary that, in the present state of coronal photography, they necessitate relative experiment with different instruments and processes side by side, and upon the corona itself.

The operation of twenty or thirty instruments by hand is out of the question, even if human nerves were infallible. To accomplish the desired end by mechanical devices three systems are feasible:

(*a*) All the mechanical movements may be effected by levers and cords and pulleys directly connected. This system was first worked out in crude form, with the contrivances at our disposal, at the eclipse station in Shirakawa, Japan, in August 1887. P. A. Engineer John Pemberton, U. S. Navy, rendered

very great assistance in the practical details. Our instruments were not of a type to lend themselves very handily to these constructions, but the lever system proved very practical and positive although cumbersome and limited in its application.

(*b*) Prior to the expedition to West Africa under my charge, for the eclipse of the 22d December 1889, a complete pneumatic system of automatic instruments had been worked out and constructed with the assistance of Professor Bigelow. Then it was demonstrated for the first time practicable for a few observers to take a very large quantity of specialized apparatus into the field, mount and adjust it, expose the plates, develop and return them to fellow investigators for whom the time and fatigue of long journeys could be spared. But most unfortunately an accident of the day in the shape of an untimely cloud precluded totality-pictures, although the multitude of novel photographic devices proved itself fully competent to the task marked out for it.

(*c*) It was not any uncertainty in the working of the pneumatic system which led to its abandonment last summer for the trial of the third or electric system of control, but rather the greater convenience in leading wires than pipes, not to say also the greater simplicity of construction and operation of the electric commutator, as described farther on. Extended experience with all three systems has convinced me that this last is decidedly the best; and it has shown itself perfectly competent to operate any available number of eclipse instruments whose record can be obtained photographically. Not only does it accomplish this accurately and positively, but it likewise makes the time-record of every automatic movement in identifiable form.

Early in the autumn of 1895 Mr. D. Willis James, a trustee of Amherst College, and his son, Arthur Curtiss James, a graduate, generously tendered the use of their splendid schooner yacht, "The Coronet," to convey an expedition to Japan for observing the total eclipse of the Sun. In August last year Mr. Pemberton was again one of my faithful coadjutors, by the

courteous permission of the Secretary of the Navy; Professor Pickering, of the Harvard Observatory, kindly gave Mr. Gerrish, well-known for his ready skill in astronomical devices and constructions, leave to accompany us; Mr. E. A. Thompson, a practical and inventive expert, was engaged as chief constructing mechanician, and our instruments were in large part built by him and his sons Herbert and Frank; and in Japan a highly skillful artist, Mr. K. Ogawa, and his assistants, were engaged for the purpose of carrying out our abundant photographic plans. Both the wet process and the dry were employed.

As in the African expedition seven years previously, the instruments were provided by the kind coöperation of many individuals and institutions, to whom full credit is given in the report of our expedition. In all twenty photographic instruments were worked into the automatic system, and complete preparations were made which, but for an unhappy repetition of our experience in West Africa, would have given us more than four hundred exposures with several types of reflecting and refracting telescopes, photographic doublets, a pair of spectroscopes, photometers, and a pair of polariscopes.

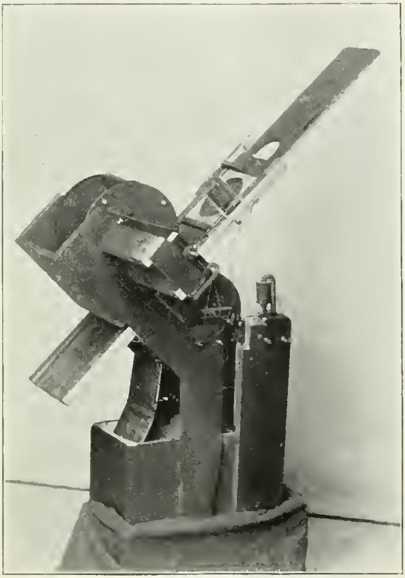
The precision of working of all this complicated system of apparatus has thoroughly convinced me of its absolute practicability. I am satisfied, too, that the mechanical principles involved have been thought out and experimented upon with such care and completeness that the detailed constructions may now be published for the benefit of others who, like myself, are convinced that the infrequent availability of eclipses renders it incumbent upon us to extend the duration of totality from three minutes to thirty on every possible opportunity.

Pending the fuller publication in the report of our expedition, in which all the constructions and devices are given with working drawings, I have pleasure in presenting to the readers of the ASTROPHYSICAL JOURNAL, by the courtesy of Professor Hale, the following description of one type of automatic movement which we found most practicable, together with a descrip-

tion of the electric commutator, by which the circuits of all the instruments were unerringly controlled.

Numerous devices for experimental shutters have been tried, but the type found best adapted to quick automatic control is a hollow rotary cylinder with a clear space cut through it, as shown in Plate XXIII (upper left-hand side). Alternate quarter turns open and close it, and the rotation is under the precise, speedy, and effective control of an electric escapement permitting only a single quarter turn at each closing of the circuit. Below it and to the right is shown the plate movement. It is a four-sided barrel, whose revolution is effected by a long and powerful spiral spring wound round its journal. The "fly" of a striker movement in an ordinary clock is connected with a pulley on the axis of the plate-barrel, and serves to make its working positive and yet not too rapid. This device is perhaps the best of our constructions; it keeps abundant power in proper check, and the detent-pins on the face of the barrel stop without any jar on meeting the escapement-pallets. Freedom from jar is a fundamental essential in all the automatic movements when several instruments are mounted on the same polar axis; for the tremor of the shutter and plate movement of one might ruin the definition of another where an exposure is in progress. The plates are slipped into holders strung together in a jointed but inextensible chain, which passes over the four-sided plate drum. A long chain of plates of any desired size is easily within the capacity of this construction. The heaviest loads thrown upon instruments of this type were a chain of 24 plates 8×10 inches, and 150 plates $2 \times 2\frac{1}{2}$ inches. Both showed themselves capable of perfect working. The particular movement shown in the illustration handled 36 plates 4×5 inches. The large diagonal slide was constructed for automatic working by an armature as figured on its right side, gravity furnishing the power; and two orthochromatic screens, one orange and the other neutral tint, were mounted in the two apertures, and permitted to descend between barrel and shutter at the instant required. At first the plate drum and shutter were both moved independently by cir-

PLATE XXIII.



TYPE OF AUTOMATIC SHUTTER WITH
PLATE MOVEMENT.

cuits from the commutator; but in our final instruments a contact spring was attached to each shutter, and an independent circuit through it controlled the shifting of the plates.

The basis of the commutator is an old chronograph with a ten-inch cylinder. Its movement was reconstructed so as to eliminate all backlash. At the right-hand end of the barrel is a coarse feed screw, and held rigidly in gear with it by a spring is a half-nut attached to the bent arm leading upward to the sliding-board to which the contact comb is secured. The number of contact springs, or teeth of this comb, is forty-eight. The barrel revolves, like that of an ordinary chronograph, once in sixty seconds. As totality was not to exceed three minutes, the contact springs, or teeth of the comb, were placed at a distance apart equal to three threads of the feed-screw. The barrel, originally of wood, was replaced by hard-rubber ends and a periphery of thin sheets of planished copper. Small brass contact pins were secured to the cylinder wherever a contact was required by boring into the copper sheets and tapping. The pins were then screwed in firmly against a small shoulder on each, affording rigidity and perfect contact with the copper. To facilitate placing them the barrel was mounted in a lathe and a delicate spiral traced over its entire length, using the same feed employed in cutting the feed-screw for the contact comb. Exact correspondence was thus secured. At ten-second intervals fine longitudinal lines were drawn across the barrel, and the number of each tenth-second, continuously from 0 to 8640, was engraved at the point of its intersection with the spiral. By this simple device it was possible to locate the position of each pin in a few seconds, and to verify it from the complete index of contacts. This was carefully calculated in advance, and embodied the full scheme of automatic movements for each instrument. As the number of independent circuits was forty-eight, all capable of operation by the commutator for 180 seconds, and any pin could be placed with accuracy to $\frac{1}{20}$ of a second, the ultimate capacity of the instrument is expressed by the product of these, or rather more than 170,000. Above the commutator is shown the

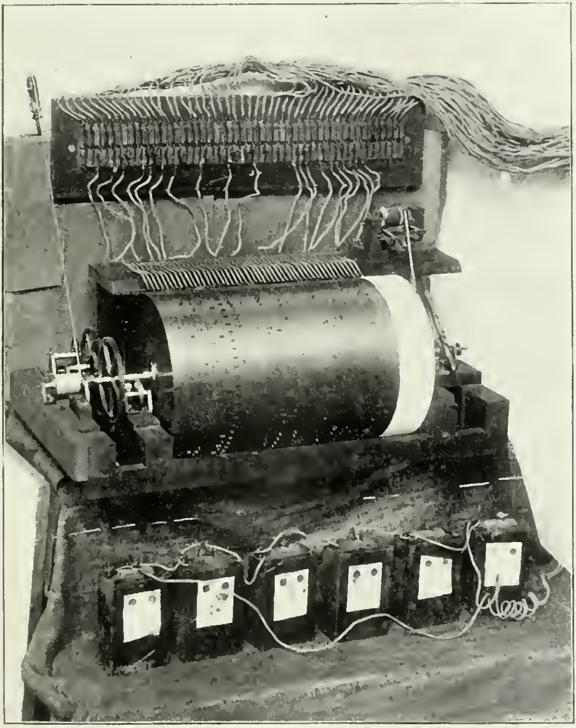
switchboard, by means of which any desired combination of instruments might be effected. It was especially useful in the preliminary experiments. The current was furnished by twelve Edison-Lalande cells of type *S* (not shown) reinforced by six dry batteries of an excellent form manufactured in Tōkyō. A fillet wound round the end of the commutator barrel recorded its running by means of a pen and clock circuit in the usual manner. Thereby the commutator performed the double duty, not only of making the exposures themselves, but of recording with precision the beginning and end of each.

Among other instruments designed and constructed by the expedition, to operate automatically by the commutator, was one which, it is hoped, may assist in the difficult task of photographing both the bright inner and the faint outer coronas on a single plate. Some, then, at least of the complex filaments may be studied throughout their entire length. At the beginning of exposure, three concentric rings and one central disk intercept all rays from the corona, except those of the outlying streamers. In proper succession the rings, followed by the disk, rise automatically, and quickly remove from the photographic field, thereby allowing a differential exposure of the inner corona in rings. As the time of exposure of each ring is controlled by the pins in the commutator barrel, it is expected that practically the whole of the corona, both outer and inner, may be correctly timed on a single plate. Six plates gave a chance to vary the relative exposure in the different rings. But this rather intricate instrument, although its mechanical movements were perfect, suffered a like fate with the others ; and it will be interesting to see what it may be competent to do on future occasions.

Of all our apparatus, however, this may be said, that it is provisionally constructed as yet; and it is hoped to try it again during the eclipse of either 1898 or 1900. Both of these are of short duration, only about two minutes, and are to be regarded simply as tentative rehearsals for the great totality of six minutes, in Sumatra, on the 18th of May, 1901.

AMHERST COLLEGE OBSERVATORY,
April 1897.

PLATE XXIV.



ELECTRIC COMMUTATOR OF THE AMHERST ECLIPSE EXPEDITION.

A METHOD OF CORRECTING THE CURVATURE OF LINES IN THE SPECTROHELIOGRAPH.

By W. H. Wright.

The question of the curvature of lines in the prismatic spectrum has been discussed from time to time, and methods of more or less theoretical validity have been proposed for its correction. Professor Stokes investigated the form of a compound prism giving straight lines, and such prisms have been constructed. In 1874 Mr. Thomas Grubb[1] suggested correction by means of a curved slit. These are so far as the writer knows the only successful methods that have been proposed. By shortening the slit, however, the effects of curvature can be reduced to a minimum and the resulting lines, when magnified, are sensibly straight. But in the case of the spectroheliograph, where a long slit is usually desirable, the curvature becomes noticeable when even moderate dispersion is used, and must be allowed for in the measurement of solar negatives; it would therefore seem desirable to eliminate this distortion if possible. I am unable to learn anything regarding the efficiency of the compound prisms mentioned above, and the plan proposed by Grubb is evidently not applicable to the spectroheliograph. In this instrument, however, only a small part of the spectrum is used at a time, and the peculiar conditions allow special methods.

Before proceeding with the discussion it may be well to call attention to a point involved in the design of that form of spectroheliograph in which the slits are stationary with regard to the prism train, and the Sun and photographic plate move. Let S' (Fig. 1) be the first slit of the instrument and S'' its image on the second slit; further let the side a'' be the image of a', and b'' of b'. Suppose now the Sun's image is caused to move over S' from a' to b'. It is evident from the most elementary considerations that the photographic plate should move from a'' to b'', other-

[1] *Proc. R. Soc.* **22**, 308.

wise the image of a point, say in a prominence, would be drawn out into a line on the plate. This line would be perpendicular to the slit, and twice as long as the slit is broad. The resultant blurring would then be a function of the width of the slit, and the maximum width of slit allowable with a system of this sort could be determined from the resolving power of the lens, the grain of the photographic plate, and the efficiency of the instrument. But an inspection of some of the prominence pictures taken at the Kenwood Observatory shows a wealth of detail which demands that every precaution be taken against blurring in future designing of the spectroheliograph. This point is very simple; it is liable to escape attention however, and affects one of the forms of instrument suggested by Mr. Newall.[1]

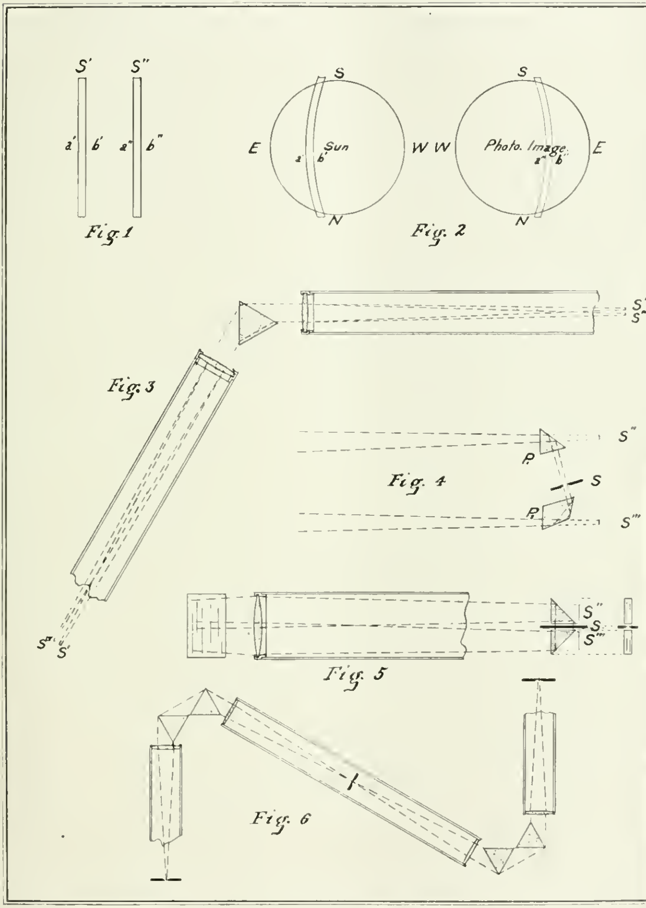
If the slits are so narrow that this astigmatism may be neglected, the distortion due to curvature may be eliminated by the following method suggested by Professor Wadsworth. The front slit is curved so as to be convex toward the edges of the prism (Fig. 2). This will flatten out the image at S'', and the curvature of S' may be so figured that S' and S'' are similar. Now if the Sun travels over S' in the direction a' b' and the plate behind S'' in the direction b'' a'', the slit curvature will be entirely corrected. The resulting negative, however, will be *reversed* when compared with an ordinary one.

The following form of instrument is mentioned with an appreciation of some of its objectionable features, among others its Littrow form, the reflections involved, and the additional absorption attendant upon the return of the light through the prisms. However, it possibly has some advantages to be indicated later and is submitted for what it may be worth.

As before let S' (Fig. 3) be the first slit, and S'' the second. By placing a mirror at S'', we could form an image of S'' at S', *i. e.*, an image of S' on itself. This image would be corrected for curvature due to prisms, and in addition to any distortions due to motions in the line of sight, and haziness caused by non-monochromatism of the light used. However, in this position

[1] *Proc. Camb. Phil. Soc.*, 9. 179.

PLATE XXV.



A METHOD OF CORRECTING THE CURVATURE OF LINES IN THE SPECTROHELIOGRAPH.

our image would avail us little. But by moving S'' to S''' we could form an image S^{iv}, which could be made to satisfy these conditions to within quantities of a negligible order by properly adjusting the line of minimum deviation within the angle $S''\,L''\,S'''$.[1] The shifting of S'' to S''' may be accomplished by reflection from an odd number of mirrors, as in Fig. 4, in which P_1 and P_2 are reflecting prisms, and S a slit, curved to admit the line desired. Instead of moving S'' to S''' we might move it directly down (perpendicular to the paper) by means of the arrangement shown in Fig. 5. This would eliminate one reflection, and would be theoretically perfect, but would necessitate longer prisms, and correspondingly larger lenses. Reflecting prisms might be introduced at S' and S^{iv} as suggested by Mr. Newall, or some other device might be adopted.

As indicated above, this instrument should correct blurring due to hazy lines, and distortions due to line-of-sight motions, when the slit may be opened wide enough to admit the whole of the distorted line. By the use of practically two spectroscopes, as indicated in Fig. 6, the principal objections to the above forms might be disposed of. This whole instrument, it will be noticed, would move in the plane of the paper, the solar image and the photographic plate remaining stationary, as in the spectroheliograph designed by Professor Hale for the late Mr. Raynard. It seems extremely doubtful however, whether the apparent advantages of such a construction would warrant the additional expense and complication.

It will be noticed that the function of the above apparatus is essentially that of a color screen, analogous in some respects to the instrument devised by Professor Wadsworth for cutting out overlapping spectra from a grating spectroscope, and described in this JOURNAL, **3**, 169–191.

YERKES OBSERVATORY,
April 1897.

[1] The indulgence of the reader is requested in reference to two oversights in the draughting of the accompanying plate. The first is the omission of the letter L'' designating the optical center of the second lens (Fig. 3), the second that of a reversing prism in Fig. 6 between the second slit and the second collimator.

SPECTROGRAPHIC OBSERVATIONS OF MARS IN 1896–7.

By James E. Keeler.

The question whether it is possible to detect the existence of water vapor in the atmosphere of Mars by means of the spectroscope has been the subject of considerable discussion in the last few years. Professor Campbell,[1] as a result of observations made with powerful apparatus under the most favorable conditions, has come to the conclusion that it is not. Mr. Jewell[2] has arrived at the same conclusion from considerations based on his studies of the telluric lines in the solar spectrum at Baltimore, and dismisses the question as one which lies far beyond our means of investigation. Even if it were possible to observe the planet with the apparatus he used for the Sun, the sensitiveness of the method would be insufficient for the purpose. On the other hand, a slight strengthening of the telluric bands in the spectrum of Mars relatively to that of the equally high Moon has been noted by skillful observers on a number of occasions. The extreme difficulty of these observations must not, however, be forgotten.

With regard to the best form of apparatus for such observations there has been some difference of opinion. Mr. Jewell holds that a high resolving power is necessary, while Mr. Campbell considers that high resolving power is not necessary or even desirable. My own experiments[3] lead me to agree with the views of Mr. Campbell. They relate, however, merely to the best means of observation. So far as the main question is concerned, it seems to me that the reasoning which Mr. Jewell applies to the case of an isolated water-vapor line is equally applicable to the lines taken collectively.

[1] *Pub. A. S. P.*, 6, 228. *Ap. J.*, 2, 28.

[2] *Ap. J.*, 3, 255.

[3] *Ap. J.*, 4, 137.

During the winter of 1896–7 I made some experiments in this direction by photographing the spectra of Mars and the Moon on the same plate. The advantages of the method are obvious. Faintness of light can be compensated for by prolonged exposure; the spectra of the two bodies can be given practically equal width and density; they are brought into juxtaposition, so that the comparison is made with the greatest ease and certainty, and a permanent record is secured, which can be consulted as often as desired. On the other hand there are some disadvantages, the chief of which is the great variation of the sensitiveness of the plate with the wave-length in the region where the water-vapor lines occur, while the delicacy of the method, as compared with that of visual observations, is open to doubt Aside from these disadvantages, the precise weight of which could only be ascertained by experiment, there was the very unfavorable condition that the atmosphere at Allegheny almost always contains a large amount of moisture. This, however, equally affects visual observations, and is not to be avoided, especially since the circumstances permit little range in the choice of nights.

The instrument used for the comparison was the Thaw spectroscope[1] mounted on the 13-inch equatorial. The collimator and the camera have each a focal length of 16 inches and an effective aperture of 1.12 inches. A single dense prism was used. It was my intention to use also the train of three prisms, but unfortunately the number of suitable nights was so small that this part of the programme could not be carried out.

Satisfactory photographs were obtained on the nights of December 13 and 16, 1896, and February 13, 1897, when the sky was what passes for clear in Allegheny. The ratio of exposure-times required to produce equal density at the D lines was determined on each evening by a preliminary experiment. On December 16 the exposures were: Moon 16^m, Mars 27^m. Both bodies were at a high altitude. The temperature was 27° and the relative humidity 77 per cent. Several plates were

[1] *A. and A.*, 12, 40.

obtained, on which the spectra of the Moon and Mars were almost exactly equal in width and density. On February 13 the disk of Mars had become so small that it was allowed to drift its own width along the slit, and the exposure was correspondingly increased.

The spectra obtained in the manner described above extend to some distance below the D lines (which are well separated on the plates), and therefore include the water-vapor band in this region, as well as the δ band farther above. But in order to show satisfactorily this extent of spectrum, at a place where the sensitiveness of an orthochromatic plate varies so rapidly with the wave-length, it was necessary to give very full exposure; and therein lies a weakness of the method, for the equalization of density produced by the full exposure also diminishes the contrast between the atmospheric band and the background of continuous spectrum. As a matter of fact, no difference whatever could be found between the spectra of the Moon and Mars, when both bodies were at a high altitude, on any of the plates, and the results of the observations being negative, I have not considered it worth while to describe them in greater detail.

In order to obtain some data for estimating the sensitiveness of the method, comparisons were made in the same way of the high and low Sun, and of the Moon near the zenith and at various lower altitudes. It was found from these comparisons that no differences in the spectra could be detected until the zenith distance of the body at the lower observation was something like 45° or 50°. A slight increase in the strength of the atmospheric bands was suspected at about this point; a decided increase took place only at a much greater zenith distance. It appears therefore that the additional effect of half such an atmosphere as the Earth's might possibly be detected by the method employed. There is every reason to suppose that no effect so great as this can be produced by the atmosphere of Mars.

These results, as far as they go, agree with those obtained visually by Mr. Campbell. I would not, however, draw any

sweeping conclusions from them, since it is quite possible that if a different dispersion had been employed, or even if the plates had been exposed or developed differently, the effectiveness of the method might have been increased.

Such observations evidently require a more favorable climate than that of the eastern United States. It seems to me that Mr. Campbell is justified in attaching great weight to the superior conditions under which his observations were made, *i. e.*, to the dryness of the air at Mt. Hamilton and the elevation of the Observatory above sea level, and also to the observation of the relative strength of the water-vapor lines in the spectrum of Mars at different parts of the disk. A glance at Mr. Jewell's diagram [1] shows that a considerable strengthening of the lines can be expected only at points very near the limb, and hence a large image, obtainable, without sacrifice of light, only with a large telescope, is required. The possibility of making satisfactory comparisons with such an instrument under the best circumstances could probably be correctly estimated only by one actually looking at the spectrum. Personally, I believe this test to be far more reliable than any other that has been proposed.

[1] *Ap. J.*, 1, 314.

ON THE INFLUENCE OF MAGNETISM ON THE NATURE OF THE LIGHT EMITTED BY A SUBSTANCE.[1]

By P. Zeeman.

1. Several years ago, in the course of my measurements concerning the Kerr phenomenon, it occurred to me whether the light of a flame if submitted to the action of magnetism would perhaps undergo any change. The train of reasoning by which I attempted to illustrate to myself the possibility of this is of minor importance at present;[2] at any rate I was induced thereby to try the experiment. With an extemporized apparatus the spectrum of a flame, colored with sodium, placed between the poles of a Ruhmkorff electro-magnet, was looked at. The result was negative. Probably I should not have tried this experiment again so soon had not my attention been drawn some two years ago to the following quotation from Maxwell's sketch of Faraday's life. Here (Maxwell, *Collected Works*, II, 790) we read: "Before we describe this result we may mention that in 1862 he made the relation between magnetism and light the subject of his very last experimental work. He endeavored, but in vain, to detect any change in the lines of the spectrum of a flame when the flame was acted on by a powerful magnet." If a Faraday[3] thought of the possibility of the above-mentioned relation, perhaps it might be yet worth while to try the experiment again with the excellent auxiliaries of spectroscopy of the present time, as I am not aware that it has been done by others.[4] I will take the liberty of stating briefly to the readers of the *Philosophical Magazine* the results I have obtained up till now.

2. The electro-magnet used was one made by Ruhmkorff and

[1] *Philosophical Magazine* [5], 43, March 1897, p. 226.

[2] *Cf.* §§ 15 and 16.

[3] See appendix for Faraday's own description of the experiment.

[4] See appendix.

of medium size. The magnetizing current furnished by accumulators was in most of the cases 27 amperes, and could be raised to 35 amperes. The light used was analyzed by a Rowland grating, with a radius of 10 feet and with 14,938 lines per inch. The first spectrum was used, and observed with a micrometer eyepiece with a vertical cross-wire. An accurately adjustable slit is placed near the source of light under the influence of magnetism.

3. Between the paraboloidal poles of an electro-magnet the middle part of the flame from a Bunsen burner was placed. A piece of asbestos impregnated with common salt was put in the flame in such a manner that the two D lines were seen as narrow and sharply defined lines on the dark ground. The distance between the poles was about 7^{mm}. If the current was put on, the two D lines were distinctly widened. If the current was cut off they returned to their original position. The appearing and disappearing of the widening was simultaneous with the putting on and off of the current. The experiment could be repeated an indefinite number of times.

4. The flame of the Bunsen was next interchanged with a flame of coal gas fed with oxygen. In the same manner as in § 3 asbestos soaked with common salt was introduced into the flame. It ascended vertically between the poles. If the current was put on again the D lines were widened, becoming perhaps three or four times their former width.

5. With the red lines of lithium, used as carbonate, wholly analogous phenomena were observed.

6. Possibly the observed phenomena (§§ 3, 4, 5) will be regarded as nothing of any consequence. One may reason in this manner: widening of the lines of the spectrum of an incandescent vapor is caused by increasing the density of the radiating substance and by increasing the temperature.[1] Now, under the influence of the magnet, the outline of the flame is undoubtedly changed (as is easily seen), hence the temperature and possibly also the density of the vapor is changed. Hence one

[1] *Cf.* however, also Pringsheim (*Wied. Ann.*, 45, 457, 1892).

might be inclined to account in this manner for the phenomenon.

7. Another experiment is not so easily explained. A tube of porcelain, glazed inside and outside, is placed horizontally between the poles with its axis perpendicular to the line joining the poles. The inner diameter of the tube is 18^{mm}, the outer one 22^{mm}. The length of the tube is 15^{cm}. Caps are screwed on at each end of the tube;[1] these caps are closed by plates of parallel glass at one end and are surrounded by little water-jackets. In this manner, by means of a current of water, the copper caps and the glass plates may be kept sufficiently cool while the porcelain tube is rendered incandescent. In the neighborhood of the glass plates, side tubes provided with taps are fastened to the copper caps. With a large Bunsen burner the tube could be made incandescent over a length of 8^{cm}. The light of an electric lamp, placed sideways at about two meters from the electro-magnet, in order to avoid disturbing action on the arc, was made to pass through the tube by means of a metallic mirror. The spectrum of the arc was formed by means of the grating. With the eyepiece the D lines are focused. This may be done very accurately, as in the center of the bright D lines the narrow reversed lines are often seen. Now a piece of sodium was introduced into the tube. The Bunsen flame is ignited and the temperature begins to rise. A colored vapor soon begins to fill the tube, being at first of a violet, then of a blue and green color, and at last quite invisible to the naked eye. The absorption soon diminishes as the temperature is increased. The absorption is especially great in the neighborhood of the D lines. At last the two dark D lines are visible. At this moment the poles of the electro-magnet are pushed close to the tube, their distance now being about 24^{mm}. The absorption lines now are rather sharp over the greater part of their length. At the top they are thicker, where the spectrum of the lower, denser vapors was observed. Immediately after

[1] PRINGSHEIM uses similar tubes in his investigation concerning the radiation of gases, *l. c.*, p. 430.

the closing of the current the lines *widen* and are seemingly *blacker;* if the current is cut off they immediately recover their initial sharpness. The experiment could be repeated several times, till all the sodium had disappeared. The disappearance of the sodium is chiefly to be attributed to the chemical action between it and the glazing of the tube. For further experiments, therefore, unglazed tubes were used.

8. One may perhaps try to account for the last experiment (§ 7) in this direction: it is true that the tube used was not of the same temperature at the top and at the bottom; further, it appears from the shape of the D lines (§ 7) that the density of the vapor of sodium is different at different heights. Hence certainly convection currents caused by difference of temperature between the top and bottom were present. Under certain plausible suppositions one may calculate that, by the putting on of the electro-magnet, differences of pressure are originated in the tube of the same order of magnitude as those caused by the difference of temperature. Hence the magnetization will push *e. g.*, the denser layer at the bottom in the direction of the axis of the tube. The lines become widened. For their width at a given height is chiefly determined by the number of incandescent particles at that height in the direction of the axis of the tube. Although this explanation still leaves some difficulties, certainly something may be said for it.

9. The explanation of the widening of the lines attempted in § 8 is no longer applicable to the following variation of the experiment, in which an unglazed tube is used. The inner diameter of the tube, about 1^{mm} thick, was 10^{mm}. The poles of the electro-magnet could be moved till the distance was 14^{mm}. The tube was now heated by means of the blowpipe instead of with the Bunsen burner, and became in the middle part white hot. The blowpipe and the smaller diameter of the tube make it easier to bring the upper and lower parts to the same temperature. This is now higher than before (§ 7) and the sodium lines remain visible continuously.[1] One can now wait till the

[1] PRINGSHEIM, *l. c.*, p. 456.

density of the sodium vapor is the same at various heights. By rotating the tube continuously round its axis I have still further promoted this. The absorption lines now are equally broad from the top to the bottom. When the electro-magnet was put on, the absorption lines immediately widened along their whole length. Now the explanation in the manner of § 8 fails.

10. I should like to have studied the influence of magnetism on the spectrum of a solid. Oxide of erbium has, as was found by Bunsen or Bahr, the remarkable property of giving by incandescence a spectrum with bright lines. With the dispersion used, however, the edges of these lines were too indistinct to serve my purpose.

11. The different experiments from §§ 3 to 9 make it more and more probable that the absorption—and hence also the emission lines of an incandescent vapor are widened by the action of magnetism. Now if this is really the case, then by the action of magnetism on the free vibrations of the atoms, which are the cause of the line spectrum, other vibrations of changed period must be superposed. That it is really inevitable to admit this specific action of magnetism is proved, I think, by the rest of the present paper.

12. From the representation I had formed to myself of the nature of the forces acting in the magnetic field on the atoms, it seemed to me to follow that with a band spectrum and with external magnetic forces the phenomenon I had found with a line spectrum would not occur.

It is, however, very probable that the difference between a band and a line spectrum is not of a quantitative but of a qualitative kind.[1] In the case of a band spectrum the molecules are complicated; in the case of a line spectrum the widely separated molecules contain but a few atoms. Further investigation has shown that the representation I had formed of the cause of the widening in the case of a line spectrum in the main was really true.

13. A glass tube, closed at both ends by glass plates with

[1] KAYSER in Winklemann's *Handbuch*, II, 1, p. 421.

parallel faces and containing a piece of iodine, was placed between the poles of the Ruhmkorff electro-magnet in the same manner as the tube of porcelain in § 7. A small flame under the tube vaporized the iodine, the violet vapor filling the tube.

By means of electric light the absorption spectrum could be examined. As the temperature is low this is the band spectrum. With the high dispersion used, there are seen in the bands a very great number of fine dark lines. If the current around the magnet is closed, *no* change in the dark lines is observed, which is contrary to the result of the experiments with sodium vapor.

The absence of the phenomenon in this case supports the explanation, that even in the first experiment, with sodium vapor (§ 7) the convection currents had no influence. For in the case now considered, the convection currents originated by magnetism, which I believed to be possible in that case, apparently are insufficient to cause a change of the spectrum; yet, though I could not see it in the appearance of the absorption lines (*cf.* § 7), the band spectrum is, like the line spectrum, very sensible to changes of density and of temperature.

14. Although the means at my disposal did not enable me to execute more than a preliminary approximate measurement, I yet thought it of importance to determine approximately the value of the magnetic change of the period.

The widening of the sodium lines to both sides amounted to about $\frac{1}{40}$ of the distance between the said lines, the intensity of the magnetic field being about 10^4 C. G. S. units. Hence follows a positive and negative magnetic change of $\frac{1}{40000}$ of the period.

15. The train of reasoning mentioned in (1), by which I was induced to search after an influence of magnetism, was at first the following: If the hypothesis is true that in a magnetic field a rotary motion of the ether is going on, the axis of rotation being in the direction of the magnetic forces (Kelvin and Maxwell), and if the radiation of light may be imagined as caused by the motion of the atoms, relative to the center of mass of the molecule, revolving in all kinds of orbits, suppose for simplicity, circles; then the period, or what comes to the same, the

time of describing the circumference of these circles, will be determined by the forces acting between the atoms, and then deviations of the period to both sides will occur through the influence of the perturbing forces between ether and atoms. The sign of the deviation, of course, will be determined by the direction of motion, as seen from along the lines of force. The deviation will be the greater the nearer the plane of the circle approximates to a position perpendicular to the lines of force.

16. Somewhat later I elucidated the subject by representing to myself the influence exercised on the period of a vibrating system if this is linked together with another in rapid rotary motion. Lord Kelvin (now forty years ago)[1] gave the solution of the following problem: Let the two ends of a cord of any length be attached to two points at the ends of a horizontal arm made to rotate round a vertical axis through its middle point at a constant angular velocity, and let a second cord bearing a material point be attached to the middle of the first cord. The motion now is investigated in the case when the point is infinitely little disturbed from its position of equilibrium. With great angular velocity the solution becomes rather simple. Circular vibrations of the point in contrary directions have slightly different periods. If for the double pendulum we substitute a luminiferous atom, and for the rotating arm the rotational motion about the magnetic lines of force, the relation of the mechanical problem to our case will be clear.

It need not be proved that the above-mentioned considerations are at most of any value as indications of somewhat analogous cases. I communicate them, however, because they were the first motive of my experiments.

17. A real explanation of the magnetic change of the period seemed to me to follow from Professor Lorentz's theory.[2]

In this theory it is assumed that in all bodies small electri-

[1] *Proc. R. Soc.*, 1856.

[2] LORENTZ, *La Théorie électromagnétique de Maxwell*. Leyde, 1892; and *Versuch einer Theorie der electrischen und optischen Erscheinungen in bewegten Körpern*. Leyden, 1895.

cally charged particles with a definite mass are present, that all electric phenomena are dependent upon the configuration and motion of these "ions," and that light vibrations are vibrations of these ions. Then the charge, configuration, and motion of the ions completely determine the state of the ether. The said ion, moving in a magnetic field, experiences mechanical forces of the kind above mentioned, and these must explain the variation of the period. Professor Lorentz, to whom I communicated these considerations, at once kindly informed me of the manner in which, according to his theory, the motion of an ion in a magnetic field is to be calculated, and pointed out to me that, if the explanation following from his theory be true, the edges of the lines of the spectrum ought to be circularly polarized. The amount of widening might then be used to determine the ratio between charge and mass, to be attributed in this theory to a particle giving out the vibrations of light.

The above-mentioned extremely remarkable conclusion of Professor Lorentz relating to the state of polarization in the magnetically widened lines I have found to be fully confirmed by experiment (§ 20).

18. We shall now proceed to establish the equations of motion of a vibrating ion, when it is moving in the plane of (x, y) in a uniform magnetic field in which the magnetic force is everywhere parallel to the axis of z and equal to H. The axes are chosen so that if x is drawn to the east, y to the north, z is upwards. Let e be the charge (in electro-magnetic measure) of the positively charged ion, m its mass. The equations of relative motion then are:

$$\left.\begin{aligned} m\frac{d^2x}{dt^2} &= -k^2x + eH\frac{dy}{dt} \\ m\frac{d^2y}{dt^2} &= -k^2y - eH\frac{dx}{dt} \end{aligned}\right\} \qquad (1)[1]$$

The first term of the second member expresses the elastic force drawing back the ion to its position of equilibrium; the

[1] These equations are like those of the Foucault pendulum, and of course lead to similar results.

second term gives the mechanical force due to the magnetic field. They are satisfied by

$$\left.\begin{aligned} x &= \alpha e^{st} \\ y &= \beta e^{st} \end{aligned}\right\} \qquad (2)$$

provided that

$$\left.\begin{aligned} m s^2 \alpha &= -k^2 \alpha + e H s \beta \\ m s^2 \beta &= -k^2 \beta - e H s \alpha \end{aligned}\right\} \qquad (3)$$

where m, k, e are to be regarded as known quantities.

For us the period T is particularly interesting. If $H = 0$, it follows from (3) that

$$S = i \frac{k}{\sqrt{m}} = i \frac{2\pi}{T}$$

or

$$T = \frac{2\pi\sqrt{m}}{k}. \qquad (4)$$

If H is not 0, it follows from (3) approximately that

$$S = i \frac{k}{\sqrt{m}} \left(1 \mp \frac{eH}{2k\sqrt{m}}\right).$$

Putting T' for the period in this case, we have

$$T' = \frac{2\pi\sqrt{m}}{k} \left(1 \pm \frac{eH}{2k\sqrt{m}}\right). \qquad (5)$$

Hence the ratio of the change of period to the original period becomes

$$\frac{eH}{2k\sqrt{m}} = \frac{e}{m} \cdot \frac{HT}{4\pi}. \qquad (6)$$

A particular solution of (1) is that representing the motion of the ions in circles. If revolving in the positive direction (viz., in the direction of the hands of a watch for an observer standing at the side towards which the lines of force are running) the period is somewhat less than if revolving in the negative direction. The period in the first case is determined by the value of (5) with the minus sign, in the second with the plus.

The general solution of (1) shows that the ions describe, besides circles, also slowly rotating elliptical orbits. In the general case, the original motion of the ion having an arbitrary position in space, it is perfectly clear that the projection of the

motion in the plane of (x, y) has the same character. The motion resolved in the direction of the axis of z is a simple harmonic motion, independent of and not disturbing the one in the plane of (x, y), and hence one not influenced by the magnetic forces. Of course, the consideration of the motion of an ion now given is only to be regarded as the very first sketch of the theory of luminiferous motions.

19. Imagine an observer looking at a flame placed in a magnetic field in a direction such that the lines of force run towards or from him.

Let us suppose that the said observer could see the very ions of § 18 as they are revolving; then the following will be remarked: There are some ions moving in circles and hence emitting circularly polarized light; if the motion is round in the positive direction the period will, for instance, be longer than with no magnetic field; if in the negative direction, shorter. There will also be ions seemingly stationary and really moving parallel to the lines of force with unaltered period. In the third place there are ions which seem to move in rotating elliptical orbits.

If one desires to know the state of the ether originated by the moving ions one may use the following rule, deduced by Professor Lorentz from the general theory: Let us suppose that in a molecule an ion P, of which the position of equilibrium is P_0, has two or more motions *at the same time*, viz., let the vector P_0P always be obtained by adding the vectors P_0P which should occur in each of the component motions at that moment; then the state in the ether at a very great distance in comparison with P_0P will be obtained by superposing the states which would occur in the two cases taken separately.

Hence it follows in the first place that a circular motion of an ion gives circularly polarized light to points on the axis of the circle.

Further, one may choose instead of the above-considered elliptical orbits a resolution more suited to our purpose. One may resolve the motion of the ion, existing before the putting

on of the magnetic force, into a rectilinear harmonic motion parallel to the axis of z and two circular (right-handed and left-handed) motions in the plane of (x, y).

The first remains unchanged under the influence of the magnetic force, the periods of the last are changed.

By the action of the grating the vibrations originated by the motion of the ions are sorted according to the period, and hence the complete motion is broken up into three groups. The line will be a triplet. At any rate one may expect that the line of the spectrum will be wider than in the absence of the magnetic field, and that the edges will give out circularly-polarized light.[1]

20. A confirmation of the last conclusion may be certainly taken as a confirmation of the guiding idea of Professor Lorentz's theory. To decide this point by experiment, the electro-magnet of § 2, but now with pierced poles, was placed so that the axes of the holes were in the same straight line with the center of the grating. The sodium lines were observed with an eyepiece with a vertical cross-wire. Between the grating and the eyepiece were placed the quarter-undulation plate and Nicol which I formerly used in my investigation of the light normally reflected from a polarly magnetized iron mirror.[2]

The plate and the Nicol were placed relatively in such a manner that right-handed circularly polarized light was quenched. Now according to the preceding the widened line must at one edge be right-handed circularly polarized, at the other edge left-handed. By a rotation of the analyzer over 90° the light that was first extinguished will be transmitted, and *vice versa*. Or, if first the right edge of the line is visible in the apparatus, a reversal of the direction of the current makes the left edge visible. The cross-wire of the eyepiece was set in the bright line. At the reversal of the current the visible line moved! This experiment could be repeated any number of times.

[1] I saw afterward that Stoney, *Trans. R. Soc., Dublin*, IV, endeavors to explain the existence of doublets and triplets in a spectrum by the rotation of the elliptical orbits of the "electrons" under the influence of perturbing forces.

[2] ZEEMAN, *Communications of the Leyden Laboratory*, No. 15.

21. A small variation of the preceding experiment is the following: With unchanged position of the quarter-wave plate the analyzer is turned round. The widened line is then, during one revolution, twice wide and twice fine.

22. The electro-magnet was turned 90° in a horizontal plane from the position of § 20, the lines of force now being perpendicular to the line joining the slit with the grating. The edges of the widened line now appeared to be plane polarized, at least in so far as the present apparatus permitted to see, the plane of polarization being perpendicular to the line of the spectrum. This phenomenon is at once evident from the consideration § 19. The circular orbits of the ions being perpendicular to the lines of force are now seen on their edges.

23. The experiments 20 to 22 may be regarded as a proof that the light vibrations are caused by the motion of ions, as introduced by Professor Lorentz in his theory of electricity. From the measured widening (§ 14) by means of relation (6), the ratio $e : m$ may now be deduced. It thus appears that $e : m$ is of the order of magnitude 10^7 electro-magnetic C. G. S. units. Of course this result from theory is only to be considered as a first approximation.

24. It may be deduced from the experiment of § 20 whether the positive or the negative ion revolves.

If the lines of force were running towards the gratings, the right-handed circularly polarized rays appeared to have the smaller period. Hence in connection with § 18 it follows that the positive ions revolve, or at least describe the greater orbit.

25. Now that the magnetization of the lines of a spectrum can be interpreted in the light of the theory of Professor Lorentz, the further consideration of it becomes specially attractive. A series of further questions already present themselves. It seems very promising to investigate the motion of the ions for various substances, under varying circumstances of temperature and pressure, with varying intensities of the magnetization. Further inquiry must also decide as to how far the strong mag-

netic forces existing according to some at the surface of the Sun may change its spectrum.

The experiments described have been made in the physical laboratory at Leyden, to the Director of which, Professor Kamerlingh Onnes, I am under great obligations for continuous interest in the present subject.

AMSTERDAM, January 1897.

APPENDIX.

Since the publication of my original paper in the *Proceedings* of the Academy at Amsterdam, and while the present paper was in the press, I have become acquainted with two attempts, till now unknown to me, in the same direction, and also with the original account of Faraday's experiment referred to in § 1. The last is to be found in Faraday's *Life* by Dr. Bence Jones, II, 449 (1870) and as it is extremely remarkable I will reprint it here:

1862 was the last year of experimental research. Steinheil's apparatus for producing the spectrum of different substances gave a new method by which the action of magnetic poles upon light could be tried. In January he made himself familiar with the apparatus, and then he tried the action of the great magnet on the spectrum of chloride of sodium, chloride of barium, chloride of strontium, and chloride of lithium.

On March 12 he writes:

Apparatus as on last day (January 28) but only ten pairs of voltaic battery for the electro-magnet.

The colorless gas flame ascended between the poles of the magnet, and the salts of sodium, lithium, etc., were used to give color. A Nicol's polarizer was placed just before the intense magnetic field, and an analyzer at the other extreme of the apparatus. Then the electro-magnet was made, and unmade, but not the slightest trace of effect on or change in the lines in the spectrum was observed in any position of polarizer or analyzer.

Two other pierced poles were adjusted at the magnet, the colored flame established between them, and only that ray taken up by the optic apparatus which came to it along the axis of the poles, *i. e.*, in the magnetic axis, or line of magnetic force. Then the electro-magnet was excited and rendered

neutral, but not the slightest effect on the polarized or unpolarized ray was observed.

This was the last experimental research that Faraday made.

In 1875 we have a paper by Professor Tait, who has kindly sent me a copy, "On a Possible Influence of Magnetism on the Absorption of Light, and some correlated subjects" (*Proc. R. Soc. Edinburgh*, session 1875–6, p. 118). Professor Tait remarks that a paper by Professor Forbes read at the Society, and some remarks upon it by Maxwell, have recalled to him an experiment tried by him several times, but which hitherto has led to no result. Then the paper proceeds:

The idea is briefly this: The explanation of Faraday's rotation of the plane of polarization of light by a transparent diamagnetic requires, as shown by Thomson, molecular rotation of the luminiferous medium. The plane-polarized ray is broken up, while in the medium, into its circularly polarized components, one of which rotates with the ether so as to have its period accelerated, the other against it in a retarded period. Now, suppose the medium to absorb one definite wave-length only, then — if the absorption is not interfered with by the magnetic action — the portion absorbed in one ray will be of a shorter, in the other of a longer, period than if there had been no magnetic force; and thus, what was originally a single dark absorption line might become a double line, the components being less dark than the single one.

Hence here the idea is perfectly clearly expressed of the experiment, tried in vain; an idea closely akin to that of § 15 above, both being in fact founded on Kelvin's theory of the molecular rotation of the luminiferous medium, though not directly applicable to the experiment of § 9, in which case the lines of magnetic force are perpendicular to the axis of the tube.

In the second place I have to mention two papers by the late M. Fievez, to which attention has been drawn by M. van Aubel, in a letter to Professor Onnes and intended for communication to the Academy of Sciences, Amsterdam. Professor Onnes read the letter at the January meeting, and made at the same time some explanatory remarks of which in the following I make free and extensive use. The papers referred to are: M. Fievez, "De l'Influence du Magnétisme sur les Caractères

des Raies spectrales" (*Bulletin de l'Acad. des Sciences de Belgique*, 3e série, tome 9, 381, 1885); and Fievez, "Essai sur l'Origine des Raies de Fraunhofer, en rapport avec la Constitution du Soleil" (*l. c.*, 3e série, tome **12**, 30, 1886). Here experiments are described as in §§ 4 and 13 of the present paper. Nothing, however, is observed about the widening of the absorption lines, nor about the polarization of the emitted light. The results obtained by M. Fievez merit careful attention and consideration. He has observed with a flame in a magnetic field not only widening but reversal and double reversal of the lines of the spectrum, the lines at the same time becoming more brilliant. Unfortunately quantitative details are not given. The facts observed in some cases by Fievez are qualitatively not in accordance with my observations or what is to be deduced from my results. Hence even in the cases where the results are qualitatively in accordance, the question remains whether Fievez has observed *the same phenomenon*. The field used by Fievez seems to have been more intense than the one I had at my disposal. Is it possible perhaps to account in this manner for the "double renversement (c'est-à-dire l'apparition d'une raie brillante au milieu de la raie noire élargie)?" I think the answer must be in the negative. For, arguing from § 19, a line must widen, or else, the field being very intense, become a triplet. We cannot but understand from Fievez's description of the experiment that the light was emitted perpendicular to the lines of force. Now the double reversed line of Fievez is not the triplet to be expected from theory, for it is expressly stated by Fievez that the line experimented upon is not the simple line of the spectrum, but one previously widened and reversed (by some agency independent of magnetism). By the action of magnetism a brilliant line in the center of the black line appears. Hence perhaps one may interpret the case of double reversal as a direct action of magnetism, but then only as a doubling of the absorption line and not as a division of the original lines into three parts. As the application of Lorentz's theory given in § 18 is confessedly only a very first sketch,

further theoretical and experimental evidence is wanted before we are to able to decide whether in the experiment of Fievez a specific action of magnetism on light or perturbing circumstances have been prevalent. Indeed one may make the same objection to M. Fievez's experiment as I myself have made to my own analogous experiment in § 6.

The whole of the phenomena observed by Fievez can readily be attributed to a change of temperature by the well-known actions of the field upon the flame (change in its direction or outline, magnetic convection, etc.); and the last sentence of his paper states that "les phénomènes qui se manifestent sous l'action du magétisme sont identiquement les mêmes que ceux produits par une élévation de température." The negative result obtained by Fievez with absorption spectra would without further consideration (as in § 12) point in the same direction. The inference to be drawn from Fievez's experiments alone would rather be, I think, that the temperature of the flame is changed in his experiments than that a specific action of magnetism on the emission and absorption of light exists. By experiments already in progress I hope to settle the dubious points.

Summarizing we may say: Had the experiments of Fievez come to my knowledge they would have been a motive for me to further investigation, Fievez not having prosecuted his inquiry up to a decisive result. At least at present it remains even doubtful whether the phenomenon observed by Fievez with a magnetized flame is really to be attributed to *the specific action of the magnetic field on the period of the vibrations of light*, which I have found and undoubtedly proved by the experimental confirmation of Lorentz's predictions.

AMSTERDAM, February 1897.

Minor Contributions and Notes.

CURVATURE OF THE SPECTRAL LINES.[1]

In Scheiner's *Spektralanalyse der Gestirne* is given the equation of the curve of the lines as seen in a prism spectroscope. There is no demonstration offered but the reader is referred to a paper by Dit-

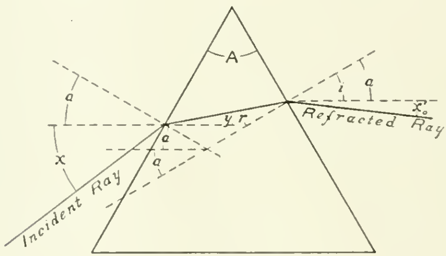


Fig. 1.

scheiner. As this paper is inaccessible to a great many interested in spectroscopic work, and as this equation can be deduced in a very simple manner, I venture to offer my own demonstration as I give it to my students in astrophysics.

Let $h =$ the angle any incident ray makes with the principal section of the prism.

$x =$ the angle its projection on the principal section makes with the bisectrix of the angle between the normals to the two faces of the prism.

$x' =$ the same for the refracted ray.

$y =$ the same for the ray inside the prism.

$a =$ half the angle between the normals to the faces of the prism.

$n =$ the index of refraction.

[1] Since the above was written my attention has been called to a paper on the same subject, by Mr. W. H. M. Christie, published in the *Monthly Notices* for March, 1874. His method of proof is, however, somewhat different from mine and his final results are not in quite the same form as those given in Scheiner.

Then we have from Mascart, *Traite d'Optique*, Tome I., page 85,

$$\sin(a+y) = \frac{\cos h}{\sqrt{n^2 - \sin^2 h}} \sin(a+x) = B \sin(a+x) \qquad (1)$$

$$\sin(a-y) = \frac{\cos h}{\sqrt{n^2 - \sin^2 h}} \sin(a+x') = B \sin(a+x') \qquad (2)$$

add and subtract (1) and (2)

$$2 \sin(a) \cos(y) = B[\sin(a+x) + \sin(a+x')] \qquad (3)$$

$$2 \cos(a) \sin(y) = B[\sin(a+x) - \sin(a+x')] \qquad (4)$$

Square (3) and (4), divide by $\sin^2(a)$ and $\cos^2(a)$ respectively, add and reduce:

$$\left.\begin{aligned}\sin^2(2a) = B^2 \{&[\sin^2(a+x) + \sin^2(a+x')] \\ &+ 2\cos(2a)\sin(a+x)\sin(a+x')\}\end{aligned}\right\} \qquad (5)$$

Substitute the value of B in (5),

$$\left.\begin{aligned}\frac{\sin^2(2a)[n^2 - \sin^2 h]}{\cos^2 h} = &\sin^2(a+x) + \sin^2(a+x') \\ &+ 2\cos(2a)\sin(a+x)\sin(a+x').\end{aligned}\right\} \qquad (6)$$

It is evident that with a straight slit for all values of h, x is constant, but x' varies. When $h = 0$ let $x' = x_0'$. When $h = 0$ (6) becomes

$$\left.\begin{aligned}n^2\sin^2(2a) = &\sin^2(a+x) + \sin^2(a+x_0') \\ &+ 2\cos(2a)\sin(a+x)\sin(a+x_0').\end{aligned}\right\} \qquad (7)$$

Subtract (7) from (6),

$$\left.\begin{aligned}&\sin^2(2a)\left[\frac{n^2 - \sin^2 h}{\cos^2 h} - n^2\right] = \sin^2(a+x') - \sin^2(a+x_0') \\ &+ 2\cos(2a)\sin(a+x)[\sin(a+x') - \sin(a+x_0')] \\ &= [\sin(a+x') - \sin(a+x_0')][\sin(a+x') \\ &+ \sin(a+x_0') + 2\cos(2a)\sin(a+x)]\end{aligned}\right\} (8)$$

$$\left.\begin{aligned}&= 2\cos\left(a + \frac{x' + x_0'}{2}\right)\sin\left(\frac{x' - x_0'}{2}\right) \\ &\left[2\sin\left(a + \frac{x' + x_0'}{2}\right)\cos\frac{x' - x_0'}{2} + 2\cos(2a)\sin(a+x)\right]\end{aligned}\right\} (9)$$

For small values of h, we may put $\cos\frac{x' - x_0'}{2} = 1$, $a + \frac{x' + x_0'}{2} = a + x_0'$, etc.

$$\left.\begin{aligned}&\sin^2(2a)\left[\frac{n^2 - \sin^2 h}{\cos^2 h} - n^2\right] = 4\cos(a + x_0') \\ &\left[\sin(a+x_0') + \cos(2a)\sin(a+x)\right]\sin\frac{x' - x_0'}{2}.\end{aligned}\right\} (10)$$

When h is small the left hand side reduces to $(n^2-1)\sin^2(2a)\sin^2(h)$.

Let r = the angle between the ray inside the prism and normal to the second face of the prism.

i = the angle between the normal to the second face and last direction of the ray.

A = prism angle, then $i=(a+x_0')$ $2a=A\sin(a+x)=n\sin(A-r)$. In the notation of Scheiner $\sin(h)=\frac{Z}{f}=h$ nearly, $x'-x_0'=-\frac{X}{f}$, collimator and observing telescope having the same focal length. Making these substitutions (10) becomes, since $\sin\frac{X}{f}=\frac{X}{f}$, nearly,

$$(n^2-1)\sin^2 A\left(\frac{Z^2}{f^2}\right)=-2\cos(i)\left[\sin(i)+n\cos(A)\sin(A-r)\right]\frac{X}{f},$$

since $\sin(i)=n\sin(r)$.

$$Z^2=-\frac{2fn\cos(i)\left[\sin(r)+\cos(A)\sin(A-r)\right]X}{(n^2-1)\sin^2(A)}$$

$$Z^2=-\frac{2nf\cos(i)\cos(A-r)}{(n^2-1)\sin A}\cdot X$$

which is Scheiner's formula.

H. C. Lord.

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ERRATA.

In Dr. Brace's "Note on Steady Liquid Surfaces" in this Journal, **5**, March 1897, p. 215, line 9, for 1″ read 0.′1.

In Professor Campbell's article in this Journal, **5**, April 1897, p. 236, line 12, for Oct. 22, *1895* read Oct. 22, *1896*.

STARS HAVING PECULIAR SPECTRA.[1]

A list of stars having peculiar spectra is given in the annexed table. With four exceptions noted below they were all discovered by Mrs. Fleming in her regular examination of the Draper Memorial photographs. The designation of the star, its approximate right ascension and declination for 1900, its catalogue magnitude, and a brief description of its photographic spectrum are given in the successive columns of the table. When the object is not a catalogue star its

[1] Harvard College Observatory, *Circular No. 17*.

position as derived from a photograph, is given in the notes following the table.

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h m			
....	0 25.6	−46° 58′	..	Type III. Hydrogen lines bright. Variable.
....	5 35.1	−69 52	..	Gaseous Nebula. Gal. long. 247° 08′, lat. −31° 43′.
A.G.C. 6633	5 36.0	−34 8	2.5	$H\beta$ bright, superposed on broad dark line. α Columbae.
A.G.C. 9313	7 14.5	−24 47	4.6	Peculiar. 30 Can. Maj. Resembles ζ Puppis.
A.G.C. 10182	7 43.9	−25 42	5.3	$H\beta$ bright. *o* Puppis.
−41° 3911	8 10.8	−41 24	10.	$H\beta$, $H\gamma$, $H\delta$, and $H\zeta$ bright. Resembles η Carinae.
A.G.C. 12465	9 4.8	−70 8	5.2	$H\beta$ bright, superposed on broad dark line. E Carinae.
A.G.C. 17542	12 48.8	−56 37	5.5	$H\beta$ bright. Companion to μ Crucis.
....	13 31.1	−55 58	..	Peculiar. Variable.
A.G.C. 19273	14 8.0	−56 37	5.6	$H\beta$ bright.
....	16 21.1	−43 26	..	Type IV.
A.G.C. 22640	16 39.2	−46 54	7.4	Bright band, wave-length about 4700.
−36° 11341	17 7.0	−37 0	9.1	Gaseous Nebula. Gal. long. 317° 13′. lat. −0° 45′.
....	17 11.6	−45 52	..	Type IV.
−7° 4689	18 39.1	− 7 12	8.2	$H\beta$ bright.
−7° 5141	19 55.7	− 7 39	9.8	Type IV.
....	20 8.5	−44 43	..	Peculiar. Variable.
A.G.C. 29191	21 11.5	−39 15	7.3	Peculiar.
A.G.C. 31272	22 55.0	−23 4	8	Peculiar.

The position of the first star is R. A. $=0^h\ 24^m\ 23^s.9$, Dec. $-47^\circ\ 6'\ 3''$ (1875). Dr. De Lisle Stewart, at Arequipa, called attention to the spectrum of this star on a plate taken with the Bruce 24-inch telescope, adding the remark "bright lines (hydrogen?)." On examination by Mrs. Fleming it proved to be variable, having a spectrum of the type characteristic of such stars.

The position of the second object which is in the larger Magellanic Cloud is R. A. $=5^h\ 35^m\ 20^s.0$, Dec. $-69^\circ\ 52'\ 51''$ (1875).

The bright band in ζ Puppis having wave-length 4688 is dark in the spectrum of 30 Canis Majoris. This spectrum, like that of the adjacent star, 29 Canis Majoris, was found by the writer to contain the additional hydrogen lines having wave-lengths 3925, 4027, 4202, and 4544.

The bright line in the spectrum of o Puppis was found independently by Dr. Stewart.

The position of the ninth star is R. A. $= 13^h\ 29^m\ 32^s.3$, Dec. $-55°\ 50'\ 10''$ (1875). The spectrum of this star may resemble that of ζ Puppis, since it contains two bright lines which may coincide with the lines having wave-lengths 4633 and 4688 in the spectrum of that star. ζ Puppis, 29 Canis Majoris, 30 Canis Majoris, and this star may form a subdivision of Type V. All of these stars are near the central line of the Milky Way.

The bright line in the spectrum of *A. G. C.* 19273 was found by Miss A. J. Cannon.

The position of the eleventh star is R. A. $= 16^h\ 19^m\ 15^s.9$, Dec. $-43°\ 22'\ 49''$ (1875).

The thirteenth object, $-36°$ 11341, is *N. G. C.* 6302.

The position of the fourteenth star is R. A. $= 17^h\ 9^m\ 46^s.1$, Dec. $-45°\ 49'\ 44''$ (1875).

The position of the seventeenth star is R. A. $= 20^h\ 6^m\ 45^s.2$, Dec. $-44°\ 46'\ 59''$ (1875). Dr. Stewart noted "bright line star (faint)" on a Bruce photograph. An examination by Mrs. Fleming shows that the star is variable and that the spectrum is peculiar.

DISTRIBUTION OF STARS IN CLUSTERS.

Professor Bailey has recently made a count of the stars in the vicinity of several clusters. An enlargement was made of a photograph of the Pleiades taken with the Bruce telescope and having an exposure of six hours. A region 2° square, with η Tauri (Alcyone) in the center was divided into 144 smaller squares, each 10′ on a side. The stars in each of these squares were then counted. The total number thus found was 3972, an average of 28 in each square. The 42 squares including the brighter stars in the group contain 1012 stars, an average of 24 per square. It therefore appears that the total number of stars in the region of the Pleiades is actually less than that in adjacent portions of the sky, of equal area, and it is much less than the corresponding number in many parts of the Milky Way. The Pleiades must, therefore, be regarded, first as a group consisting of comparatively bright stars; secondly, if we omit the bright stars, the number of faint stars will be much less than in the adjacent portions of the sky. This absorption of the faint stars is probably due to the nebulosity surrounding this group. A similar absence of faint stars is noticeable near other diffused nebulae, for example, that surrounding *N. G. C.* 6726–7. This condition would be explained if we assume

that stars have not yet been formed by the condensation of this portion of the nebula or that the latter is less distant and slightly opaque.

A similar count was made of ten regions $6'$ square, in the vicinity of η Carinae. The plate used was taken with the 24-inch Bruce telescope, and had an exposure of four hours. From this count it appears that in a region 5° square, and represented in Plate 2, described in *Circular No. 15*, the total number of stars was about 250,000, while the number contained on the entire plate exceeded 400,000.

EDWARD C. PICKERING.

March 30, 1897.

Reviews.

ELECTRO-MAGNETIC WAVES.

JOSEPH HENRY in 1842 writing in regard to the oscillatory character of a Leyden jar discharge says: "A remarkable result was obtained in regard to the distance at which induction effects are produced. A single spark about an inch long produced an induction sufficiently powerful to magnetize needles at a distance of 30 feet," and he is "disposed to adopt the hypothesis of an electrical plenum . . . . and it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from a flint and steel in the case of light." (*Scientific Writings of Joseph Henry*, I, 203.) Since then, Maxwell, following the ideas obtained from experiment by Faraday, has developed the theory of magnetic action which requires a medium through which electro-magnetic effects are propagated with the velocity of light. Twenty-five years after this theory was published methods of exciting and observing these waves were worked out by Hertz.

Apparatus.—As is well known Hertz excited waves of comparative shortness by the oscillatory discharge between bodies of low capacity and induction. His vibrator consisted of two zinc plates about 40^{cm} square to which were soldered rods ending in brass balls between which the discharge took place. To excite this system the terminals of the secondary of an induction coil are connected to either plate. Succeeding experimenters have not changed the principle of exciting, the only variation being the reduction of the capacity and self induction of the system by diminishing the dimensions. Such a system generates electro-magnetic waves. These waves are propagated through the ether, being composed of an electrical displacement and a magnetic displacement at right angles to each other, both being perpendicular to the line of propagation. For some experiments they may be conveniently guided along wires. E. Lecher (*Wiener Berichte*, p. 340, 1890) describes a method for this which has been much used. Opposite each of the two plates of a Hertz vibrator an equally large plate is arranged and from each plate is led a long wire, the two wires being parallel. The waves are thus guided along these wires, the produc-

tion of waves in these secondary wires being a phenomenon of resonance.

To detect the waves excited in the ether Hertz used a ring of wire in which a spark gap was inserted. When placed in certain positions relative to the vibrating system surgings were set up in the ring and minute sparks appeared at the spark gap. He called this a resonator, because the sparks were strongest when the natural period of the ring was the same as that of the vibrator. In order to obtain a linear detector the ring resonator has been replaced by two linear resonators, placed along a straight line with the spark gap between the adjacent ends. When these experiments are tried on a small scale the sparks are extremely difficult to observe. To overcome this the spark gap has been replaced by a thermal junction, and the throw of a galvanometer caused by the heating of this junction is taken as a measure of the intensity of the surgings. (Klemencie, *Wied. Ann.*, **42**, 416. Lebedew, *Wied. Ann.*, **56**, 1.) This method has been successfully applied to quantitative work in a particularly skillful manner by Lebedew, who has observed waves of a length $\lambda = 0^{cm}.6$ to $0^{cm}.3$.

Rutherford has developed a method which consists of connecting the ends of the resonators to a minute solenoid wound directly on a core composed of a number of fine steel wires. The method of observation is, (1) magnetize the steel wire core to saturation, (2) observe the deflection of a magnetometer needle due to the steel core, (3) connect the solenoid to the ends of the resonator and if surgings be started in the resonator the oscillatory current through the solenoid will tend to demagnetize the core, (4) again observe the deflection of the magnetometer due to the core. The difference between the deflection when the core was saturated and the last deflection is taken as a measure of the electrical radiation. He has only applied it to comparatively long waves. He finds it extremely sensitive, obtaining effects at a distance of one-half mile after the waves had passed through several brick walls and a number of buildings. (*Phil. Trans.*, **189**, 1–24, 1897.)

An entirely different method of detecting these disturbances depends on the change of electrical resistance of a series of metallic bodies in contact when acted on by electro-magnetic waves, commonly called a coherer. (First pointed out by Branly, *Jour. de Phys.*, **4**, 273.) The coherer has been used by Lodge; and more recently Bose has perfected it. (*Proc. R. Soc.*, **59**, 160.)

Reflection.— Hertz found that when electro-magnetic waves were incident normally on a metal surface he could detect points along the normal for maximum and minimum sparking of the resonator. This demonstrated that the phenomenon was of the nature of a wave motion, the observed points being the loops and nodes of the standing waves caused by the interference of the incident and reflected ray (*Wied. Ann.*, 34, 609). Further it shows that the velocity of propagation is finite. Hertz considered that twice the distance between points of no sparking was the wave-length, but Sarasin and De la Rue have pointed out that this distance depends entirely on the size of the resonator used.

Wave-length.— For Hertz's shortest waves the wave-length $\lambda = 24^{cm}$. By reducing the capacity and self-induction of the vibrator succeeding experimenters have reduced this as low as $\lambda = 0^{cm}.3$ (Lebedew, *Wied. Ann.*, 56, 1). Waves between the length $\lambda = 0^{cm}.3$ and Langley's longest heat wave, $\lambda = 0^{cm}.0015$ (Keeler, ASTROPHYSICAL JOURNAL, 3, 63) yet remain to be observed.

Rectilinear propagation.— If the vibrator be placed in the focal line of a cylindrical parabolic mirror and if the laws of reflection are the same as those for light, then the waves from the vibrator will emerge from the mirror as a parallel beam. And if this beam is incident on a similar mirror placed opposite, whose focal line is parallel to the focal line of the first, a linear resonator placed on this focal line will be excited. Further, if a metal screen of size equal to the opening of the mirror be placed directly between the mirror, no effect is produced by the vibrator on the resonator, thus showing approximate rectilinear propagation (*Wied. Ann.*, 36, 769).

Polarization. If the waves composing the above beam follow the laws of light waves, the beam emerging from the parabolic mirror is plane polarized. This may be experimentally proved by rotating the receiving mirror and resonator about the ray as an axis. The action in the resonator becomes more and more feeble, and when the focal lines of the two mirrors are at right angles no effect is obtained, the two mirrors acting like polarizer and analyzer. And if the radiation pass a grating of parallel conducting wires only the electrical vibrations perpendicular to the wires will be transmitted, and the ray is plane polarized. By using two such gratings and crossing the wires at different angles, circular and elliptical polarization may be produced.

The question as to whether the electrical or magnetic displacement

is perpendicular to the plane of polarization has been investigated by Trouton (*Nature*, 39, 172). When a polarized beam is incident on a non-conducting surface at the polarizing angle, $\tan^{-1}\mu$, he found that if the electrical displacement is in the plane of incidence none of the radiation is reflected, if the magnetic displacement is in the plane of incidence a portion of the radiation is reflected. Therefore, in a plane polarized beam the electrical vibration is perpendicular to the plane of polarization. The disturbance considered by Fresnel is the electrical displacement, while that of Mac Cullagh is the magnetic displacement; and Maxwell's theory that the magnetic force is in the plane of polarization is verified.

Refraction of the beam takes place when passing from one insulating medium to another. Hertz showed this by observing the change in direction of the beam caused by a large pitch prism and thus calculated the index of refraction. A large number of measurements of indices of refraction have since been made by this and other methods. Bose points out that an excellent way to determine the index is to observe the angle of total reflection (*Proc. R. Soc.*, 59, 160).

Double refraction was demonstrated by Righi (*Mem. R. Accad. delle Scienze, Bologna* (4), 4, 487; *Wied. Ann.*, 55, 389) and simultaneously by Mack (*Wied. Ann.*, 54, 342). If the mirrors be set with their focal lines at right angles, in general the resonator is not excited. But if a block of wood be placed between them so that the grain is perpendicular to the line of propagation of the ray and at 45° to the focal lines of the mirrors, the resonator will be excited, due to what may be called double refraction by the wood. Lebedew has investigated double refraction in crystals and carried the analogy to optics so far as to construct Nicol prisms and $\frac{1}{4}\lambda$ plates (*Wied. Ann.*, 56, 1). Bose noted that the absorption was greater when the electrical vibrations are parallel to the fibrous direction in the crystal and least when perpendicular to the fiber. Bose had measurements made of the conductivity in the two directions and concludes that the absorption in various directions is proportional to the conductivity in these directions (*Proc. R. Soc.*, 60, 433).

Interference of electro-magnetic waves in air was observed by Hertz in his original experiments on reflection. A recent application of interference is that of Bose (*Proc. R. Soc.*, 60, 167) for obtaining a *pure spectrum of electric radiation* by means of diffraction gratings, the gratings being formed by strips of foil. The spectrum found appears well

defined, linear and not continuous. By this method the wave-length may be accurately determined. Interference has been of particular value in studying the propagation of the waves along a resonating system of parallel wires, as described by Lecher (*Wiener Berichte*, p. 340, 1890). If a rarefied tube be placed between the ends of the wires, it will glow, on account of the electrical oscillation in the wires. If the parallel wires be connected by a cross wire, the luminosity in general ceases. If the wire bridge be moved back and forth along the wires some sharply defined positions of the bridge are found which cause the tube to become luminous; and from a knowledge of these positions and the lengths of the wires the wave-length is determined.

Barton, with an electrometer to detect the nodes and loops, has investigated the effect of replacing a portion of the parallel wires by conductors with a capacity per unit length different from the original wires. He considers, (1) the partial reflection at the beginning of the abnormal part, (2) the partial reflection at the end of the abnormal part, (3) the interference between the two sets of waves thus reflected. He finds that as the length of the abnormal part is increased the total energy of the reflected wave is periodically increased and decreased. Thus the experiment is parallel to the optical phenomenon of *Newton's Rings*, the abnormal part of the wire corresponding to the air film. (Final paper, *Proc. R. Soc.*, **57**, 68.) In such experiments as the last the reflection of waves from the ends of the wires is troublesome. Barton describes a method for overcoming this (*Phil. Mag.*, **43**, 39).

Dispersion.—Garbasso and Aschkinass (*Wied. Ann.*, **53**, 534) constructed a prism inclosed in which were a number of tinfoil strips to act as resonators, the strips being all of the same dimensions. On passing the usual parallel beam of wave through this prism, and examining the transmitted wave by resonators of different periods they appear to find dispersion into a sort of spectrum. If this experiment be correct it supports Helmholtz's theory of dispersion. Garbasso and Aschkinass think it shows that the simple two-sphere generator gives waves of various periods which are refracted at different angles. This is contrary to theory and to the experiment of Bose with diffraction gratings. (*Proc. R. Soc.*, **60**, 167.)

Drude, while working on dispersion, found that waves 10^{cm} long are much more strongly damped in alcohol and especially in glycerine than in water or aqueous salt solutions. Theoretically the damping should increase with the conductivity, but the badly conducting liquids

are found to damp electrical waves as much as a 5 per cent. solution of copper sulphate, which is some thousand times better conductor. That is, alcohol and glycerine give absorption bands for waves of 10^{cm} length, which would indicate, according to the common theory of absorption, that the molecules of these compounds have a free period corresponding to a period of a 10^{cm} wave. In this same investigation Drude further notes that glycerine and alcohol show anomalous dispersion for waves of about the above length. (*Wied. Ann.*, 58, 1.)

Relations of K and μ.—A result of Maxwell's electro-magnetic theory of light is that the square of the index of refraction is equal to the specific inductive capacity of the substance. For some permanent gases, liquid hydrocarbon, sulphur, and paraffin, the relation approximately holds, but in general K, the specific inductive capacity, as measured in a slowly varying field, is greater than μ^2. J. J. Thompson (*Proc. R. Soc.*, 46, 292) and Blondlot (*C. R.*, 112, 1058, 1891) find that if the specific inductive capacity be determined for electrical waves of high frequency the value of K decreases as the period of the waves becomes shorter. They therefore consider it probable that if K could be measured for waves of the same length as those used to determine the index of refraction the above relations would more nearly hold. On the other hand, E. Lecher (*Phil. Mag.*, 31, 172) finds that the value of K increases as the period decreases.

Velocity.—Another conclusion from Maxwell's theory is that the velocity of electro-magnetic waves guided by a wire is equal to their velocity in air, this velocity being identical with the velocity of light.

By observing the lengths of the standing waves in a secondary circuit tuned to resonance with the vibrator, and calculating the period of the vibrator from Lord Kelvin's formula for the period of a condenser discharge, $T = 2\pi\sqrt{LC}$, E. Lecher obtained a value for the velocity along wires within about 2 per cent. of the velocity of light (*Wiener Berichte*, p. 340, 1890). Sarasin and De la Rue have demonstrated that the velocity along wires is the same as that in air (*Arch. de Genève*, 29, 358, 441, 1893, extract of same, *Nat.*, 48, 252). The same investigators, by observing the nodes in the stationary waves obtained by reflection from a large metallic mirror, and using the calculated period of the vibrator, find the velocity in air to be approximately the velocity of light (*Phys. Gesell. Berlin*, Jan. 6, 1893, extract in *Nat.*, 47, 336). Blondlot, still using the calculated period and thus making the result not yet independent of theory, found $v = 2.976$

$\times 10^{10\,\text{cm}}$ per second (*C. R.*, **113**, 628, 1891). From the same experiment $v = 3.028 \times 10^{10\,\text{cm}}$ per second with the period as recalculated by Mascart (*C. R.*, **118**, 277, 1894). By actually observing the time required for a discharge to travel a wire 1029^{m} long Blondlot found $v = 2.964 \times 10^{10\,\text{cm}}$ per second. Another experiment over 1821^{m} wire gave $2.980 \times 10^{10\,\text{cm}}$ per second. His method for observing the time of propagation was to photograph by a rotating mirror a spark through a short circuit and also the spark which had traversed the measured wire. As both sparks were caused by the same condenser discharge the interval of time between the two measures the time required by the second spark to traverse the wire (*C. R.*, **117**, 543, 1893).

Trowbridge and Duane also used a method for determining v depending on the principle of resonance. A primary oscillator and secondary circuit were tuned to resonance, and the nodes and loops of the stationary waves set up in the secondary were measured by means of a bolometer. The period was obtained by photographing the secondary spark after reflection from a rotating mirror. Thus, knowing wave-length and period, v is directly calculated. They found for v, $2.816 \times 10^{10\,\text{cm}}$ per second (*Am. Jour. Sci.*, **49**, 297, April 1895), and later after some improvements, $v = 3.0024 \times 10^{10\,\text{cm}}$ (*Am. Jour. Sci.*, **50**, 104, August 1895). By a similar method Saunders obtains as the most probable result $v = 2.997 \times 10^{10}$ (*Phys. Rev.*, **4**, 81). Thus the velocity of electric propagation is identical with the velocity of light.

(Reference should be made to a book which contains the best systematic account of the subject: "L'Ottica delle Oscillazioni Elettriche," Augusto Righi, Bologna.)

GEO. W. MIXTER.

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April 1897.

Elementary Text-book on Physics. By ANTHONY and BRACKETT. Revised by W. F. MAGIE. Wiley & Sons, New York, 1897, pp. 512.

WE HAVE before us a thoroughly modern work — modern in the best sense of the word — embodying the views of the best men of all times, including our ablest contemporaries, a work which is the product of no small amount of experience.

To one who has waded through the disconnected pages of Ganot or Deschanel, impressed mainly by the multiplicity of apparatus

employed in the study of physics, to one who has thus familiarized himself with many methods and has yet to learn good method, the present volume will prove very refreshing.

The subjects treated do not differ essentially from those discussed in the majority of texts. The same may be said of the order of the treatment. As exceptions to the two statements just made may be mentioned nine pages devoted to gravitational potential, a two-page summary of results from Helmholtz's *Memoirs on Vortex Motion*, ten pages given to the simpler mathematics of the kinetic theory of gases, and a couple of pages on Ewing's *Molecular Theory of Magnetism*.

If then it be asked what is the distinguishing feature of the book, the reply is unity of method in treatment. Fields of force and equipotential surfaces are introduced in the discussion of general dynamics; waves are first presented, under the mechanics of fluids, by a summary, perhaps too short, of the work of the Weber brothers. A general treatment of waves is prefixed also to the discussion of sound. The result is that the potential theory and the theory of waves may thereafter be freely used throughout the book. And in general the treatment of sound, heat, light, electricity, and magnetism may be described as dynamical.

This method is by no means exclusively true of the book before us. The altogether excellent *Theory of Physics* by Ames presents in a most admirable manner the unity of the subjects studied under the head of physics.

There are, however, some omissions which we cannot help wishing Professor Magie had seen fit to make. Among these may be cited the *unproved* expression for the amount of twist (angular displacement) produced in a given wire by a given couple (Eq. 47), or Ampère's expression for the action of one current element upon another (Eq. 103). If one of the chief aims of laboratory work be to discourage the all too easily acquired habit of taking things for granted, may it not be wise, in the lecture room, to reduce to a minimum the formulæ which we ask the student to take without proof.

As illustrating what your reviewer considers always desirable may be cited the articles on the "Propagation of Sound," where the student is *not* left with the bare assertion that

$$V = \sqrt{\frac{E}{D}}$$

but is furnished with the rigid proof of Rankine. The same might

have been done in as simple a way (Tait's demonstration) for the speed of transversal disturbances in strings,

$$V=\sqrt{\frac{T}{\mu}}$$

But one does not need to teach physics very long to find that however excellent a text-book may be, considered alone and by itself, it is a matter of no small difficulty for any instructor other than the author to use the book in his class room. It is, therefore, very much to be hoped that, in the near future, universities will be able to employ men who are competent to write their own books, and who prefer to write their own books, and that the universities will make it possible for these men to print their own books. H. C.

Analyse spectrale directe des Minéraux. Par ARNAUD DE GRAMONT. Paris, Boudry et Cie., pp. 207.

THE author of this work having found that certain minerals are sufficiently good conductors to permit an electric spark to be passed between fragments used as electrodes, undertook to establish a system of direct qualitative analysis based upon observations with a small laboratory spectroscope. The method of analysis is simple, and apparently well adapted to the ordinary requirements of the chemical laboratory. A strongly condensed induction spark, taken between fragments of the mineral held in platinum clips, is examined with a direct vision spectroscope containing two compound prisms, giving an angular separation of the D lines amounting to something over 1′. In the violet the absorption of these prisms is so marked that but one of them can be employed. The observing telescope contains a scale of 250 parts, and the measures are made by simply estimating the positions of the lines with reference to the scale divisions. The wave-lengths of the standard lines used in forming the reduction curve are those of Thalén, and all the measures are therefore based upon his results. The author considers his wave-lengths to be reliable to a single Ångström unit. They are consequently better adapted to the purposes of the analytical chemist than to those of the astrophysicist.

M. de Gramont finds that the spectrum of sulphur can be obtained without the aid of a vacuum tube, by simply passing the condensed spark between two points of platinum or carbon which have been

dipped in melted sulphur and allowed to cool. The chlorides give the spectrum of chlorine in addition to that of the metal, and iodine can also be recognized in its compounds. Tables of the wave-lengths of the principal lines in the spectra of nearly one hundred minerals, with accompanying descriptive matter and several plates, complete the volume. G. E. H.

Some Experiments on Helium. By MORRIS W. TRAVERS. *Proc. R. Soc.*, **60,** 449–453, 1897.

THE investigation which forms the subject of this paper directly concerns the evidence in favor of the *mixture* theory of clèveite gas. Upon diffusing the gas through an asbestos plug, Runge and Paschen noticed a change in the relative intensity of the two sets of lines into which they had divided its spectrum. This strengthened the conclusion already drawn, that the gas is a mixture. They stated, however, that this change might have been due to the reduction of pressure, as the latter was lower in the tube containing the diffused gas than in the other. It was subsequently noticed that the gas was absorbed by the platinum deposited on the walls of the tube, and the possibility of separating the supposed constituents by a process of selective absorption suggested itself to Mr. Travers. In his experiments, a tube was filled with clèveite gas under 3^{mm} pressure, and the current turned on, resulting in the following succession of colors in the tube: (1) yellow, slightly red, (2) bright yellow, (3) yellowish green, (4) green, (5) green, with phosphorescence, (6) phosphorescent vacuum; spark between electrodes outside of tube. After testing for vacuum by means of a pump the tube was heated, resulting in the discharge of gas from the platinum, and the succession of the above colors in reversed order. This showed that all the gas had been absorbed by the platinum and was given out again under the influences of heat.

The tube was now refilled, run to state (4), and exhausted. Upon reheating we should expect a yellow or a green glow, according as the color change was due to selective absorption of a yellow constituent, or to a reduction of pressure in the tube. The resulting illumination, which was green, therefore seemed to prove it to be due to this latter cause.

The relative absorptions of different gases by the platinum is touched upon in the paper. In particular argon is found to be taken

up very slowly, and may be freed from some of its impurities in this manner.

From all that is contained in the paper there seems to have been no systematic observation of the relative intensities of the spectral lines during the changes described, casual reference to the green line only appearing. In view of the systematic variation in each of the two sets reported by Runge and Paschen, and referred to above, it is to be regretted that the experiments were not extended so as to confirm it. However, the paper is a valuable contribution, and coming as it does when the status of the *mixture* theory is somewhat doubtful, its appearance is most opportune.

W. H. Wright.

Yerkes Observatory,
April 1897.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

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NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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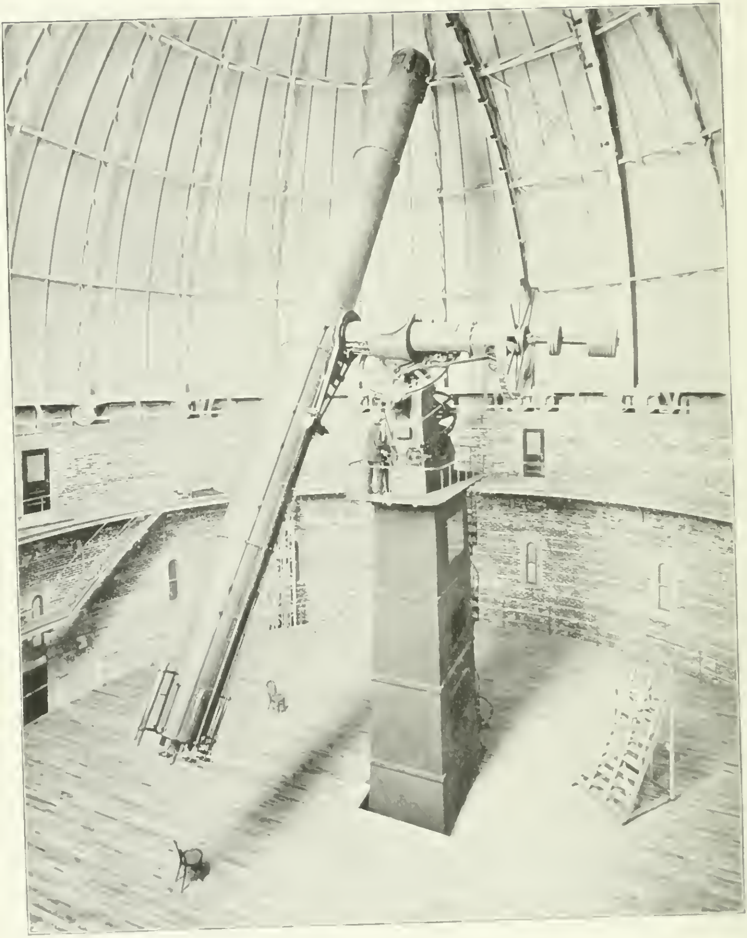


THE FORTY INCH YERKES TELESCOPE, MAY 11, 1897.

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME VI JUNE 1897 NUMBER 1

SPECTRAL PHOTOMETRIC STUDIES.

By D. W. Murphy.

DETERMINATION BY MEANS OF THE ROTATING SECTOR OF THE RELATION OF SPECTRUM INTENSITY TO THE WIDTH OF THE COLLIMATOR SLIT.

Among the different methods of comparing the intensities of two spectra that of Vierordt is the most common. The instrument used, in its simplest form, differs from the ordinary spectrometer only in the arrangement of the collimator slit. When the apparatus is to be used for photometric purposes the collimator slit is replaced by two separate slits located one directly above the other. The width of each slit is measured by means of a micrometer screw, and each in turn may be lighted from either of the sources whose intensities are to be compared.[1] The spectra thus formed are situated one above the other, and are separated by a narrow dark band.

The observations are made by means of an ocular which, being supplied with an adjustable slit, allows all the spectrum to be cut off except that part in which the comparisons are to be made. The two fields are brought to the same intensities by varying the widths of the two parts of the double collimator

[1] When measuring the amount of absorption both spectra are lighted from the same source, and the absorption medium is placed between the light and one of the slits.

slit. From the relations of the slit widths for equal intensities in the different parts of the spectrum, the intensity for different colors is found. According to Vierordt we assume that the intensity of a spectrum so lighted is directly proportional to the width of the collimator slit. When the two spectra are of the same intensity the lights are inversely proportional to their respective slit widths.

We shall investigate under what conditions this principle introduced by Vierordt is correct, both for unilateral and for bilateral slits. We know for both cases that when the width of the slit is doubled, twice the amount of light comes to the field of the observer.

The question which we are then called upon to solve is, does the doubling of the amount of light in this manner double the intensity of every part of the spectrum?

Let us imagine, first, an infinitely narrow slit; the spectrum from such a source may be called a pure spectrum, since any point in it will contain light of but one wave-length. If this slit be moved in a direction perpendicular to the edge of the prism the spectrum will travel in the same direction; and a stationary point, as the light traveled over it, would be illuminated by light of different colors. Next, let us consider a wide slit, and think of its being divided into infinitely narrow ones; we recognize that every part of the spectrum from such a source will consist of lights of different wave-lengths superposed upon each other. Such a spectrum we will call an impure one, and it is with such that we are required to deal in practical measurements.

With a unilateral slit only waves that are either greater or less, depending upon the direction of the opening of the slit, than the fundamental wave, will be superposed upon it. If a bilateral slit is used the extra waves which are brought to a given point, due to the opening of the slit, will be both greater and less than the fundamental wave.

From the above consideration it follows: that with a unilateral slit the law of proportionality holds only when the intensities of the adjacent parts of the spectrum are the same; or,

where the curve of intensity is parallel to the one axis of coördinates. With the bilateral slit the law holds where the curve of intensity is a straight line, and may be true for other curves in the region of inflection points. In the latter case the differentials of the increase in intensities due to the light from the opposite sides of the slit, must be equal and of opposite signs.

According to the measurements of Fraunhofer, Koenig, Brodhun and others, the distribution of intensity in the spectrum of the Sun and other incandescent bodies corresponds approximately to the curve shown in Fig. 1.

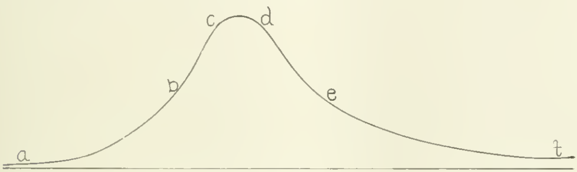


Fig. 1.

The abscissae represent the wave-lengths, and the ordinates the corresponding intensities. From this curve it follows that the unilateral slit is to be used only in those parts of the spectrum where the curve of intensity is parallel to the axis. This is true for only a small part of the spectrum in the region *cd*. The bilateral slit, on the other hand, will give true results not only at *cd*, but in the vicinity of the two points *b* and *e*. When the curve is convex to the axis, as at *ab* and *ef*, the increase in intensity must be more rapid than the increase in the slit width. If the curve is concave to the axis, as at *bc*, the increase in intensity is less rapid than that of the slit width.

In order to prove the correctness of these inferences, and to determine the magnitude of the deviation from the law of proportionality, the following observations were made.

Method of observation and apparatus used.—The photometer measurements were made with the Lummer-Brodhun spectral

photometer, a complete description of which may be found in the *Zeitschrift für Instrumentenkunde* for April 1892. This instrument differs in two respects from the spectrometers of Vierordt and others. First, it is supplied with two collimator tubes, C and C', placed perpendicular to each other (see Fig. 2); and, second, the observations are made, not by means of an ocular, but by bringing the eye directly before the slit o. The plane

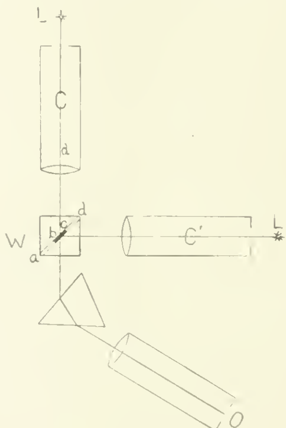


FIG. 2.

ad, which is the hypotenuse of the photometer cube W, passes through the axis of the instrument. The field ab, cd is lighted from the source L', and the field bc, from L.

The superiority of this instrument over the Vierordt and other similar spectral photometers, lies in the greater accuracy of the photometric comparisons. The fields to be compared are not separated by a dark band, but the boundary is absolutely sharp, and disappears altogether when equal intensity is obtained. The instrument allows not only this principle of likeness, but the principle of contrast[1] as well. Concerning this latter method it

[1] *Zeitschrift für Instrumentenkunde*, February 1892.

may be remarked, that the deviations in the results obtained by it are only one-eighth as great as in those obtained by the ordinary photometers.

In order to test the law of proportionality by means of the variable slit, each collimator of the spectral photometer was provided with bilateral slits. Only the one on C' was used for a comparison slit, as the weakening of the light from L was done by means of a rotating sector placed before the collimator C. According to the careful measurements made by Lummer and Brodhun with the rotating sector of the Physikalische Technischen Reichsanstalt, this method of measuring the increase or decrease of light intensity is accurate to a small fraction of 1 per cent.

The sector was driven by means of a small electric motor, and when rotated at a sufficient speed the field was perfectly clear and free from flickering; any increase in the speed beyond a certain limit gave no change whatever in the results. During the investigations the sector openings were each set at 90°, so that while in rotation the light was decreased one-half.

Various kinds of light sources were tried, but all except the incandescent electric lamp were either too weak or too inconstant to give satisfactory results. The lamps used had an intensity of about 50 candle power each, and were connected in series on the circuit of a storage battery. In order that the illumination of the two slits might be the same in all parts they were covered with milk glass plates. The plane of the lamp fiber was in each case parallel to the glass plates, and the two fibers were at equal distances from the center of the collimator slit.

The positions of the lamps were made secure by their being firmly fastened to T shaped bars, which were screwed to the base of the spectral photometer.

Before beginning the investigation some preliminary experiments were made to determine if the milk glass plates were homogeneous for the entire area to be used. To this end the slits of the collimators were made of equal widths, but both

quite narrow. With equal intensity of fields established in this way the plates were moved so that the different parts were brought over the slit. No change due to this movement, however, could be observed, and the plates were considered homogeneous in so far as their power of transmission was concerned. There was still one other possible source of error that must be investigated. The two lamp fibers were not at equal distances from all parts of the glass plates, and it was necessary to know whether this change in distance affected the uniformity of the illumination for areas as great as were to be used. Computations on this showed that for areas 1^{cm} wide the variation was not greater than 1 per cent. As the areas to be used were but little greater than 1^{mm} wide any error due to this cause was negligible.

The slit was also subjected to a special test, and by means of a micrometer microscope its widths for different readings of the slit's micrometer screw were noted. To avoid dead motion in the screw it was always turned in the same direction in making the settings for photometric equality. From readings on the width of the slit up to 2^{cm} the reading of its zero point was computed; this was to avoid any change due to tension which might be brought in were the slit to be entirely closed.

The method of taking the readings was, in principle, very simple. The two collimator slits were set at the same widths and the lamps adjusted until photometric equality was roughly obtained. The exact adjustment was then made by means of the slit of C'. A series of readings on the width of this slit for equal intensities of fields was then taken. This was for the total light from L. The sector was next started, and a second series of readings on the slit, for equal intensities, was taken. The light from L was in this case of one-half its former intensity. To check any error due to a change in the relative intensities of the two sources the sector was stopped and a second series of readings for the total light from L was taken.

In this way measurements were made for the different colors The position of the observing telescope for any desired color

was found by means of a mirror attached to the axis on which the telescope turned. This mirror reflected the image of a fixed scale, whose readings for the different wave-lengths had been previously determined.

Four independent series of measurements for the entire length of the spectrum were made. The widths of the slit ranged from approximately $0.^{mm}5$ to $1.^{mm}25$

When the principle of likeness in the photometer was used, the mean of ten readings on the width of the slit was taken. With the contrast principle the agreement was so very close that the number was reduced to five.

Results.—The numerical results are given in Tables I to IV inclusive. The wave-length of the light used is given in column 1. g is the slit width without the sector, and $2\ b$ is twice the slit width when the sector was used. These values are in terms of the divisions of the drum of the micrometer screw ($80^{\text{div}} = 1^{\text{mm}}$). δ is the percentage of difference between g and $2\ b$.

TABLE I.

λ	g	$2\ b$	δ	λ	g	$2\ b$	δ
480	52.6	53.4	−1.5	600	53.5	51.8	−3.3
500	54.0	53.6	−0.7	620	52.8	51.4	2.7
520	54.2	53.6	−1.1	640	52.9	51.4	+2.9
540	54.5	52.4	4.0	660	52.6	51.8	+1.5
560	54.4	52.8	3.0	680	51.7	52.8	—2.1
580	53.9	52.4	2.8				

TABLE II.

λ	g	$2\ b$	δ	λ	g	$2\ b$	δ
470	56.3	56.8	0.9	610	63.3	61.4	3.0
490	60.6	60.2	+0.6	630	63.4	61.6	+2.8
510	60.3	59.2	+1.8	650	63.9	62.4	2.5
530	61.1	59.6	+2.5	670	64.1	64.2	0.2
550	61.9	60.4	2.5	690	64.4	65.2	—1.2
570	62.2	61.2	1.6	700	64.3	65.4	1.7
590	63.1	60.8	+3.8				

TABLE III.

λ	g	$2b$	δ	λ	g	$2b$	δ
480	68.1	68.0	0.7	600	72.9	70.6	3.3
500	69.7	69.2	+0.7	620	73.0	71.0	2.8
530	70.3	69.4	+1.3	640	73.5	71.0	3.0
540	70.8	69.2	+2.3	660	74.4	73.2	1.4
560	71.7	69.8	+2.7	680	75.3	77.2	−2.5
580	72.5	70.8	+2.4	700	74.8	79.2	5.5

TABLE IV.

λ	g	$2b$	δ	λ	g	$2b$	δ
480	98.5	99.4	0.9	600	103.3	101.8	1.5
490	101.1	102.0	−1.9	610	103.3	101.4	+1.9
500	100.8	103.4	−2.5	620	103.3	101.8	+1.5
510	98.4	100.8	−2.4	630	103.2	102.0	+1.3
520	98.8	99.8	1.0	640	104.3	103.2	1.1
530	99.7	99.8	0.1	650	102.9	104.2	1.2
540	100.2	99.6	+0.6	660	102.3	105.8	2.4
550	100.6	100.6	0.0	670	102.8	107.2	4.1
560	101.1	100.8	+0.3	680	103.2	109.0	5.3
570	101.8	100.6	+1.2	690	103.9	112.0	7.2
580	102.2	101.0	+1.2	700	104.3	114.2	−8.7
590	102.9	101.6	+1.3				

These results show, for the light source used, that in the middle part of the spectrum the increase of the spectrum intensity is less than the increase in the slit width, that is, $g - 2b > 0$. At the ends of the spectrum just the opposite is observed. These results agree with those deduced from a consideration of the form of the intensity curve. The amounts of the deviations are different for the different wave-lengths, and, in general, are smaller for blue than for green, yellow, and extreme red. It is further shown, that for a given wave-length the deviation changes with the size of the slit used.

Heretofore the measurements have been made through the entire length of the spectrum with nearly the same width of slit, and each particular series gave the results for that width of slit only. In order to study more fully the change for varying slit widths the experiments were repeated in another form. Particu-

lar colors were examined for different slits, from the smallest to the largest size with which the measurements were possible. In this manner results were obtained for the wave-lengths 540, 590, and 690 $\mu\mu$. In Tables V to VII, inclusive, the results are shown. In these results *g*, *b*, and δ have the same significance as in the results previously given.

TABLE V. ($\lambda = 540\mu\mu$.)

g	$2b$	δ	g	$2b$	δ
13.0	14.4	−9.8	68.1	67.0	+1.7
17.7	19.0	−6.8	82.7	81.6	+1.4
27.7	28.2	−1.8	103.3	101.6	+1.7
38.0	37.8	+0.5	123.4	122.0	+1.2
53.2	52.0	+2.3	143.1	140.0	+2.2

TABLE VI. ($\lambda = 590\mu\mu$.)

g	$2b$	δ	g	$2b$	δ
13.1	14.4	−9.0	68.5	67.0	+2.2
18.0	19.0	−5.3	84.3	82.0	+2.9
27.9	28.6	−2.4	104.3	101.8	+2.5
38.6	38.0	+1.6	124.0	120.0	+3.6
53.8	52.2	−3.1	145.9	140.1	−4.1

TABLE VII. ($\lambda = 690\ \mu\mu$.)

g	$2b$	δ	g	$2b$	δ
13.3	14.6	9.0	69.4	70.2	−1.1
18.1	19.2	−6.0	86.7	88.4	−1.9
28.5	29.0	1.7	107.2	110.2	−2.7
38.4	38.8	−1.0	126.6	135.0	6.2
54.4	54.6	0.4	147.8	159.6	−7.4

These tables show, in the first place, a concordance with the former ones; at least they lead to the same general conclusions. Beyond this they teach, that for slit widths below a certain value, for every wave-length $g - 2b$ becomes < 0; that is, the intensity decreases more rapidly than the width of the slit.

The reason for this is most probably the loss of light by diffraction which occurs with narrow slits, and which causes a loss of light proportionally greater as the slit becomes narrower.

With such narrow slits the accurate determination of the zero point is a matter of much importance, and no doubt small inaccuracies arise from this source. It is not probable, however, that with the method used for the determination of the zero point the error is sufficient to change the general conclusions to be deduced.

The results do not give any general law as to the limit of exactness to be obtained by the Vierordt method of measuring the light intensity. In fact any general law is impossible, since it varies with the relative intensities and the kind of lamps to be compared.

We may conclude, however, that the assumption that the spectrum intensity is proportioned to the width of the slit is not strictly true, and it is to be used with caution; that in the blue and central parts of the spectrum it is in error for slits in the ratio of 1 to 2 as much as 2 or 3 per cent., while in the red this error may become as great as 10 per cent. This shows that this method of measuring light intensity is, in exactness, far behind the present methods of photometric comparisons, at least with such an instrument as the Lummer-Brodhun spectral-photometer. This apparatus gives with the intensity of light used an exactness of adjustment of about 0.3 per cent. Also by means of the rotating sector the same accuracy for decreasing the light is obtained, even when the sector openings are small.

INVESTIGATION OF THE TRUTH OF THE FRESNEL FORMULA FOR THE INTENSITY OF REFLECTED LIGHT, AND THE DEPENDENCE OF THIS INTENSITY ON THE COLOR OF THE LIGHT USED.

Since Fresnel, from a theoretical consideration, gave his celebrated formula for the amount of light reflected from the surface of a transparent medium, the experimental verification of it has been a problem of interest to investigators in optical

science. And of all the methods used, the photometer—the simplest in principle—was applied relatively very late. This is probably due in a large degree to the hitherto inexactness of photometric measurements which, with the small amount of light reflected, gave rise to serious errors.

It is for this reason that Professor Rood,[1] who was the first to investigate the subject, prefers measuring the amount of light transmitted by thin plates of glass, and from these results to compute the reflection at the first surface. Lord Rayleigh,[2] and shortly after him Sir John Conroy[3] were the first to choose the experimentally difficult, but decidedly less objectionable, method of measuring directly the amount of the reflected light. In order to prevent the great loss of light by diffusion which takes place in the ordinary photometers, Rayleigh dispensed with the use of diffusion screens and used only direct reflection from the light source to the eye. He observed from the amount of light reflected from the surface of glass prisms that only those surfaces which had been freshly polished gave results consistent with theory. Conroy measured not only the light reflected, but also that transmitted by glass plates, hoping in this manner to find an explanation for the differences which so often exist between observed and computed results. He concluded that the amount of light reflected from a glass surface varies with the kind of polish to which the surface has been treated.

Even though a sufficient reason for taking up the subject anew might be found in the variations of results heretofore obtained, I had still another purpose in so doing. Rayleigh and Conroy in their investigations used white light, and as a basis for their calculations used the refractive index of the color of greatest intensity. They further used ordinary unpolarized light, while the Fresnel formula is deduced from a consideration of lights polarized in and perpendicular to the plane of incidence. A much more complete test of the formula would, therefore, be

[1] *American Journal of Science*, 50, 1.

[2] *Proc. R. Soc.*, 41, 275.

[3] *Phil. Trans.*, Vol. A 1889, p. 245.

obtained by working with light polarized at different angles to the plane of incidence. So far as I know, no investigations had been made on the amount of the reflection for lights of different colors, and no experiments that have been carried on in a purely photometric way, show that the amount of reflection is different for the different wave-lengths of the light used.[1] By means of the linear bolometer, Rubens has investigated the Fresnel formula in the ultra-red part of the spectrum, and has found that the amount of energy reflection varies for different wave-lengths.

In the following I shall show, that with the aid of the Lummer-Brodhun spectral photometer, in connection with a rotating sector for measuring the weakening of the light, and a secondary spectrometer for determining the angle of incidence of the reflected ray, we can measure the amount of reflection for any wave-length and for any desired angle of incidence. By using a Nicol placed in the path of the ray it is possible to extend those measurements to light polarized in any desired plane. The measurements to be made with special care, however, are those which show the relations of the intensities of the different colors in the spectra of the direct and reflected light.

Method of investigation and description of the apparatus.— In Fig. 3 is shown a horizontal cross section of the apparatus giving the arrangement of the different parts. The spectral photometer consists of the tubes C, C' and T, the photometer cube W, and the refracting prism P. C and C' are the collimators

[1] The Fresnel formula,

$$I_r = I\,\tfrac{1}{2}\left[\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)}\right],$$

in which I_r is the amount of light reflected, I_i the incident, i the angle of incidence, and r the angle of refraction. This formula shows that as n (the refractive index) increases, sin $(i-r)$ becomes larger, and, up to a certain point, where $(i+r=90°)$, sin $(i+r)$ becomes smaller. The same is true of the second term. The formula then says that for a given angle of incidence the amount of reflection will be a function of the refractive index, and if this index be increased the amount of reflection will be increased. We can further deduce, that since the change in the amount of reflection is a transcendental function, it will be different for different angles of incidence.

by means of which the light rays from the sources *L* and *L'* are rendered parallel before reaching the photometer *W*. *T* is the observing telescope and is provided with a variable ocular slit *o*. When the apparatus is in adjustment an eye placed before *o* sees the photometer fields lighted from the illuminated slits *s* and *s'*. The light sources used, *L* and *L'*, consisted of incandescent electric lamps of approximately fifty candle power each. The lamps were joined in series to a circuit, and supplied with a

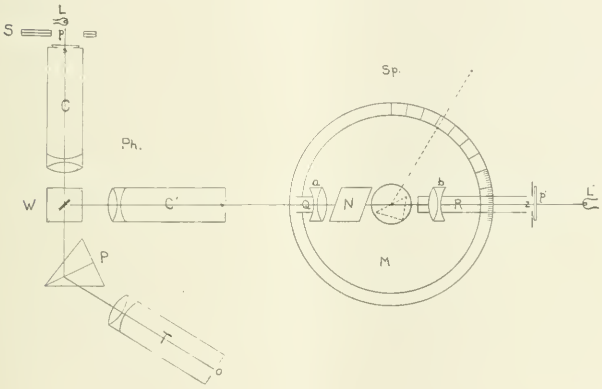


FIG. 3.

current from a storage battery, having an E. M. F. of thirty-two volts. The light source *L* is firmly fastened to an arm of the spectral photometer, and always lights in the same manner the one field of the photometer *W*. The other light source, *L'*, is mounted upon a separate piece of apparatus, *Sp*. This apparatus, which is a form of spectrometer, consists essentially of the circular plate *M* to which are fastened the arms *Q* and *R*. The plate *M*, whose diameter is about 50^{cm}, is turned from a heavy slab of slate, and its edge, being graduated, serves as the

spectrometer circle. The metal arm R, which carries the lamp L', is so mounted that it turns about an axis through the center of M, and its position is read by means of the graduated circle. The arm Q is firmly fastened, and always retains the same position relative to the spectrometer disk. The lamp L' is enclosed so that the only light emitted from it is through the slit z. The slit z and the collimator slit s are covered with milk glass plates p and p', the purpose of which is to give a more uniform field than could be got from the lamp direct. The lenses a and b are mounted so as to slide along the arms Q and R in the path of the ray. These lenses are so adjusted that the light from z passes in parallel rays from b to a, and is brought to a focus again on the slit s'.

The spectrometer as a whole is so placed that when the arm R is at its zero position, that is, making an angle of 180° with Q, the axis of the spectrometer cuts the straight line passing through the center of W and the slits s' and z. The pencil of light between b and a will then be concentric with the line of collimation of C', and will cut the spectrometer axis at right angles. When viewed with an ocular placed before o the images of s and s' will be seen to exactly coincide, and the color of the two fields will, with this adjustment, be the same for all positions of the observing telescope. In order to compare the intensities of light of any desired wave-length, it is only necessary to turn the telescope T until that color is brought into view.

The surface whose reflecting power is to be measured is placed upon the table of the spectrometer in such a position that it lies in the plane passing through the axis. By rotating the table the reflected light may be made to fall upon s' for all positions of the arm R.

In order to compute by means of the Fresnel formula the amount of the reflected light, one face of a Steinheil prism was used as a reflecting surface. The refractive indices of the prism for the desired wave-lengths had been carefully measured.

The light from the source L was weakened to the same intensity as that of the reflected portion from L' by means of a rotating

sector S placed between L and the slit s. The size of the sector opening could, during rotation, be changed at will from 180° to 0°, and by means of a vernier read to an accuracy of 0°.02. Upon the arm Q, and between the reflecting surface and the lens a, a Nicol prism N could be mounted. By revolving the Nicol in its mountings the light which fell upon s' could be polarized at any desired angle with the plane of incidence.

Dependence of the amount of reflection on the wave-length.—The method of finding the variation in the amount of reflection for different wave-lengths was as follows: The relation of the intensities of the light sources L and L' for two colors, first for the direct and then for the reflected light, was measured. A comparison of these ratios gave the excess of reflection for one color over that of the other.

The method of observation for this is very simple in form. First, the slits s and s' are set at approximately the same widths. With the arm R at its zero position and the sector open to nearly 180°, the lamps are adjusted until the fields are of nearly the same intensity for one color; all other conditions remaining the same, equal intensities are obtained by opening or closing the sector. After a series of ten settings has been made, and readings on the size of the sector opening taken, the observing telescope is turned so as to observe the light of the other wave-length, and a second series of sector readings for equal intensities of this color is taken.

The ratio $\frac{O_\lambda}{O_1}$, of the sector readings for the two colors, which is denoted by I_d, is the relation of the intensities of these colors in the spectrum of the direct light from L'. This relation is in terms of the spectrum from L, which may be considered of unit intensity for every wave-length.

The arm R is next moved from its zero position, and the reflecting surface placed on the table of the spectrometer. In order to bring the photometer fields to the same intensity when using only the reflected portion of the light from L', it would require a very considerable diminution of the sector. Measure-

ments made in this way do not possess the highest degree of accuracy on account of the smallness of the sector opening. To avoid this source of inaccuracy the sector was left at its original size, and the light source L removed until the intensities were approximately equal.

The values of O_λ' and O_l' for the reflected ray were then obtained in the same manner as for the direct ray. The quotient, $\frac{O_\lambda'}{O_l'}$, is denoted by I_r. From a consideration of the above we have $\frac{I_r}{I_d}$ as the relation of the reflection of light of wave-length λ to that of light of wave-length l.

For example, the readings of the half-sector openings for wave-lengths $535\mu\mu$ and $670\mu\mu$, for the direct light were $O_\lambda = 81°.33$ and $O_l = 75°.76$ (λ being considered as wave $535\mu\mu$ and l as wave $670\mu\mu$).

The value of I_d was therefore $\frac{81.33}{75.76} = 1.074$. For the light reflected at incidence angle of 20° the results obtained were $O_\lambda' = 80°.25$ and $O_l' = 73°.35$. From this $I_r = 1.094$ and $\frac{I_r}{I_1} = 1.019$. This shows that for light of wave-length $535\mu\mu$. 1.9 per cent. more light is reflected than for light of wave-length $670\mu\mu$.

TABLE I.

Relations of the amounts of light reflected for λ $535\mu\mu$ and $670\mu\mu$.

Incidence angle	Observed	Computed
20	1.019	1.015
40	1.010	1.015
60	1.010	1.008
80	1.003	1.002

The results of these investigations for different incidence angles are given in Table I. The computed values are the ratios of the amounts of reflection taken from the results computed by the Fresnel formula for the corresponding angle of incidence

and for the refractive indices of the glass for wave-lengths $535\mu\mu$ and $670\mu\mu$. [See Table III.]

Character of light reflected from colored plates.— Measurements were made on the intensity of the different colors of the spectrum for lights reflected from different colored glass. For this purpose, glass plates, the reverse side of which had been covered with asphalt black, were used. Red, as well as blue, glasses gave for the blue a stronger reflection than for the red rays, showing that the composition of the reflected light is not changed by the color of the reflecting medium. These results were not compared with theory, since the refractive indices of the plates for different wave-lengths of light could not be readily determined.

Measurement of the amount of light reflected for different colors and at different angles of incidence.— The problem of measuring the absolute amount of light reflected is in theory a very simple one. For its solution it is necessary only to compare the total incident light from L' with the reflected portion. This is done by taking the sector readings for equal intensities of the photometer fields with R at its zero position and at the position of the desired angle of incidence. The comparison of the direct with the reflected light, however, is attended with two experimental difficulties. First, the reflected portion is small, being, for the smaller angle of incidence, only about 4 per cent. of the total incident light. Second, the reflected light, more especially for large angles of incidence, is partly polarized at the reflecting surface. The first condition leads to the measuring of small sector openings, the adjustment and reading of which require especial care to prevent error.

The polarizing of the light at the reflecting surface may lead to another source of error, since in the spectral photometer the refracting prism also produces polarization, and in this case acts as an analyser in destroying the light which has been polarized by reflection. It is for this reason that photometers consisting simply of diffusion screens have in some cases been brought into use for measuring the amount of reflected light.

The error due to polarization may, however, be entirely avoided by placing a polarizer in the path of the ray, between the reflecting surface and the lens a. For this purpose a Nicol prism of $45^{mm} \times 45^{mm}$ opening was used. With this arrangement the measurements, for both the direct and the reflected rays, are made for light polarized in one plane whose position is identical with that of the Nicol. In order to compare the results obtained by measurements with those computed from the formula it is necessary to know accurately the polarizing plane of the Nicol. This may be found by computing from the refractive index with the help of the Brewster formula, $\mu = \tan i$, the angle of incidence under which the reflected light is totally polarized. The position of L' is adjusted by means of the movable arm R until the light falls upon the surface at this angle; the Nicol is then turned until the light which reaches the photometer from L' is a minimum. At this position the polarizing plane of the Nicol is perpendicular to the plane of incidence. By means of the graduated circle on the Nicol mounting I was able to bring the polarizing plane to any desired position and to read its position to an accuracy of $5'$.

Method of observation.— After the Nicol had been adjusted the reflecting prism was removed and the arm R placed at its zero position. By means of the rotating sector the photometer fields were brought to the same intensities, and a series of five readings on the size of the sector opening was taken. The arm was then turned to the position for the required angle of incidence, and the prism so placed that the reflected light fell upon the slit s'. Photometric equality was then brought about by closing the sector, and a series of readings on the size of the sector opening was taken. To avoid any error due to a change in the relative intensities of the light sources during the measuring process, the arm R was again placed in its zero position, the prism removed, and a second series of five readings of the sector for direct light was taken.

The ratio of the two sector openings gives the relation of the incident to the reflected light. If we consider the incident light

equal to one hundred, which has been done in the following results, the amount of the reflection is given in terms of per cent. of the incident light.

Measurements were made for light of wave-lengths 535 $\mu\mu$ and 670 $\mu\mu$, and for three positions of the polarizing plane, which were at angles of 0°, 45° and 90° with the plane of incidence.

The results are given in the following tables. I is the angle at which the incident light falls upon the reflecting surface. The observed values are the results obtained from a single series of observations, and not the mean of several sets of readings.

The computed results are deduced from the Fresnel formula:

$$I_r = I_i \tfrac{1}{2}\left[\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)}\right].$$

The refractive indices were obtained by direct measurement, and were for wave-lengths 535 $\mu\mu$ and 670 $\mu\mu$ respectively, 1.56462 and 1.55896.

The differences between the observed and computed results are given direct, and are not — owing to the different values of the reflected light — computed in terms of percentage.

These tables show in general a close agreement between the observed and computed results, the differences being in every case but a small percentage of the total incident light, while in many cases they are almost perfectly concordant. The greatest discrepancy exists for light polarized perpendicular to the incidence plane, and in this case for the small angles of incidence.

TABLE II.

Light polarized in the incidence plane.

	$\lambda = 670\ \mu\mu$			$\lambda = 535\ \mu\mu$		
I	Observed	Computed	δ	Observed	Computed	δ
20	5.60	5.58	−0.02	5.61	5.66	−0.05
40	9.24	8.94	+0.30	9.20	9.06	0.14
60	19.64	19.64	0.00	20.19	19.80	0.39
80	55.73	56.04	−0.31	56.72	56.24	−0.48

TABLE III.

Light polarized at an angle of 45° to the incidence plane.

I	$\lambda = 670\ \mu\mu$			$\lambda = 535\ \mu\mu$		
	Observed	Computed	δ	Observed	Computed	δ
20	4.80	4.80	±0.00	5.10	4.87	+0.23
40	5.60	5.38	+0.22	5.63	5.46	+0.17
60	9.62	9.87	−0.25	10.12	9.95	−0.17
80	39.07	39.65	0.56	39.04	39.73	0.69

TABLE IV.

Light polarized perpendicular to the incidence plane

I	$\lambda = 670\ \mu\mu$			$\lambda = 535\ \mu\mu$		
	Observed	Computed	δ	Observed	Computed	δ
20	4.43	4.02	+0.41	4.38	4.08	0.30
40	2.03	1.82	−0.21	2.00	1.86	−0.14
60	....	0.10	....	....	0.10	......
80	23.05	23.16	0.11	22.76	23.22	−0.46

If these many independent observations speak for the correctness of the Fresnel formula, they also give evidence of the exactness of the photometric comparisons, and of the method of measuring by means of the rotating sector despite the small amount of reflected light.

As the measurements for light polarized perpendicular to the plane of incidence could not be repeated, the spectral photometer being in use for other investigations, I am unable to give any explanation of the slightly greater variations between observed and computed results in this particular case. It is not probable that the Fresnel formula fails to give correct results in this particular case, but that the cause for these variations is to be sought for in some other source of inaccuracy.

In Table V I have given the results obtained without using the Nicol at *Q*; this will show the magnitude of the error which may affect results when the polarizer is not used as a ray filter.

TABLE V.

	$\lambda = 670\ \mu\mu$			$\lambda = 535\ \mu\mu$		
i	Observed	Computed	δ	Observed	Computed	[illegible]
20	4.70	4.80	−0.10	4.74	4.87	−0.13
40	4.60	5.38	0.78	4.62	5.46	−0.84
60	7.77	9.87	2.10	7.79	9.95	−2.16
80	34.44	39.65	−5.21	34.41	39.73	−5.32

The calculated values for the reflection of ordinary light are the same as for light polarized at an angle of 45° to the incidence plane. [Compare Table III.]

For small angles of incidence where the polarizing effect is small, the observed and computed results agree to within 2 per cent. When the angles of incidence are large this difference rises to 12 per cent. and over.

In a second work, which I hope to be able to carry out, I shall use the method described above to study the influence which the treatment and character of the surface have on the amount of the reflected light.

In conclusion I wish to express my thanks to the Physikalische Technischen Reichsanstalt for the opportunities granted me for carrying out the above investigations, and to the members of the institution for the many courtesies shown me, especially to Professor Lummer and Dr. Brodhun, to whom I am indebted for much valuable assistance.

STANFORD UNIVERSITY,
April 1897.

NOTE ON THE CHEMICAL COMPOSITION OF THE MINERAL RUTILE.

By B. HASSELBERG.

IN my researches on the arc-spectrum of titanium I employed, as elsewhere stated[1], instead of the commercial metallic powder, a Norwegian specimen of the mineral rutile, mainly on account of the far greater steadiness of the arc thus formed. According to the hitherto published chemical analyses of this mineral[2], I had no good reason to expect any foreign lines of importance other than those of iron, the more conspicuous of which would be present in any case on account of impurities in the carbons. However, upon examining the arc-spectrum of vanadium obtained from a specimen of this metal presented to Baron Nordenskiöld by Moissan of Paris, I found, to my great surprise, that several of its strongest lines coincided exactly with faint lines in my titanium spectrum, thus indicating a very appreciable percentage of vanadium in the rutile analyzed. This induced me to investigate more closely the spectra of other specimens of the mineral in question, particularly as I had the opportunity to select from among the rich collections of the Royal Mineral Cabinet varieties from different quarters of the world.

In the comparisons I have used only the part of the spectrum included between $\lambda 460$ and $\lambda 427$. This is sufficient, for in this region there is situated one of the most prominent groups of the whole vanadium spectrum, namely the group $\lambda 441$–438, the presence of which in the spectrum of any rutile, even though feeble in intensity, would indicate indubitably the presence of a sensible percentage of the metal. In order to decide definitely concerning the coincidences, the above named part of the vanadium spectrum was photographed upon the same plate with the

[1] *Svenska Vetensk. Akad. Handl.* Also *Ap. J.*, 5, 194–198, 1897.

[2] DANA, *Descriptive Mineralogy*, fifth edition. New York, 1883, p. 160.

same region of the spectra of the different rutiles, and on these plates the intensities of the rutile lines corresponding to vanadium were estimated on a scale in which 1 denotes the faintest, and 6 the strongest lines. A + or − after a number indicates the intensity of the line in question to be nearer to this number than to the next; thus 1+ denotes an intensity greater than 1, but not attaining 1.2, and so on. In this way the following table has been constructed, which contains the results of the investigation of twelve rutiles, namely:

Norway:	1.	Rutile from Krageröe.
	2.	" " Langöe.
	3.	" " Lofteshagen.
Sweden:	4.	" " Käringbricka.
Russia:	5.	" " Tachowaja, Ural.
	6.	" " Miask, Orenburg.
Switzerland:	7.	" " Binnenthal, Wallis.
France:	8.	" " Yrieix.
Germany:	9.	" " Freiberg.
Spain:	10.	" " New Castilia.
America:	11.	" " Graves Mountain, Lincoln Co.
	12.	" " Magnet Caves, Arkansas.

From Table A it will be seen that, with one exception, all the rutiles examined contain vanadium in varying proportions. This exception is found in the Anatas from Binnenthal, Canton Wallis, in Switzerland, in the spectrum of which the vanadium lines are almost absolutely wanting. This statement is not invalidated by the greater intensity of the two lines 4444.40 and 4441.90, for these lines belong without doubt to titanium, although they differ so very little in position from the vanadium lines that a separation on my spectrograms is impossible.

On comparing the intensities of the vanadium lines in the different specimens of rutile, the singular fact at once manifests itself that varieties from neighboring lodes contain a very different percentage of the metal. Thus among the Norwegian rutiles the two specimens from Langöe and Lofteshagen contain vanadium in a much larger proportion than the Krageröe rutile, and the same holds good for the two Russian and also for the American rutiles. This peculiarity finds a counterpart in the

TABLE A.

RUTILE FROM

Vanadium λ	I	Krageröe	Langöe	Lofteshagen	Käringbricka	Tachowaja	Miask	Binnenthal	Yrieix	Freiberg	Castilia	Graves Mountain	Arkansas	Remarks
4268.85	3	..	1+	...	1	1	1	...	tr.	1	1	1+	tr.	The sign tr.
71.80	3	...	...	...	1	...	...	...	...	..	...	...	...	(trace) indicates
4330.15	3	...	1	tr.	1	tr.	tr.	...	...	tr.	tr.	1	...	an intensity too
33.00	3	...	1	1	1	1	tr.	...	..	tr.	1—	1.2	...	feeble to be esti-
41.15	3	...	1+	1	1—	1	tr.	...	tr.	1—	1	1.2	tr.	mated
53.05	3.4	1	1+	1+	1.2	1+	tr.	...	tr.	1—	1	1.2	tr.	
79.42	4.5	2	3	2.3	3—	2.3	2—	tr.	2	2	2.3	2.3	2—	
84.95	4.5	2	2.3	2	2.3	2+	1.2	tr.	2—	2	2+	2	1.2	
90.15	4.5	2	2	2	2+	2	1	...	1.2	1.2	2—	2	1	
95.40	4.5	1	1.2	1.2	2	1.2	tr.	...	1+	1	1	2	1	
4400.75	4	1.2	2—	1.2	2	2	1	1	1.2	1.2	2	2	1	
06.85	4.5	...	1.2	1.2	2—	1.2	tr.	...	1	1	1+	2—	1	
07.90	4.5	1.2	2	2—	2	2—	1	tr.	1.2	1.2	2—	2+	1	
08.40	4	1.2	2—	2—	2	2	1	...	1.2	1.2	2—	2+	1+	
08.65	4.5	1.2	2	2	2	2—	1	...	1.2	1.2	2—	2+	1+	
16.65	3	2	..	.	2	...	...	...	...	..	...	.	..	
38.03	3.4	...	1	1	1	1	1	...	...	tr	tr.	1	...	
41.90	3.4	1.2	2	2—	2—	1.2	1.2	1+	..	1.2	1.2	2	1	Ti
44.40	3.4	...	2	2	1.2	1.2	1.2	1.2	..	1.2	1.2	2	1	Ti
52.12	4	...	1	1	...	1—	tr.	tr.	...	tr.	1—	1.2	..	
59.95	4	tr.	1+	1+	1.2	1.2	1—		1	1	1	1+	1	
60.45	4.5	1	1.2	1.2	2	2	1		1+	1.2	1.2	2—	1	
62.55	3.4	tr.			1	1	...		tr.	tr.		1	1	
69.90	3.4	...			1	1	tr.		tr.	tr.		1	1	
4545.62	3.4	...			1.2	1+	1		1	1		1	1+	[Co
49.85	3	3.4			3.4	3.4	3.4		3.4	3		3.4	3.4	Belongs to Ti.
77.40	4	tr.			1	1+	1—		tr.	1		1	tr.	
80.55	4	1			1.2	1.2	1		1	1+		1+	1	
80.55	4.5	1			1.2	1.2	1		1	1+		1+	1	
94.30	4.5	1			1.2	2	1		1	1+		1—	1	

case of another component of some rutiles, namely, chromium, of which metal a very notable amount was discovered in the Swedish specimen from Käringbricka as early as 1803,[1] and is now detected in some of the varieties under discussion

In order to prove that the observed titanium lines are not to be ascribed to an impurity of the carbons, the spectrum of the latter was photographed with that of vanadium before introducing rutile into the arc. Besides the ordinary carbon bands the

[1] Dana, *Mineralogy*, p. 161.

resulting plates show feebly only a few of the most conspicuous iron and calcium lines, but of vanadium not the least trace is seen. The purity of the carbons analyzed is thus to be considered as entirely satisfactory.

While the presence of vanadium in the rutile thus forms a hitherto entirely unknown feature of this mineral, the presence of chromium in the Swedish variety was, as above stated, detected by chemical analysis as early as 1803, and has since then been verified in some other specimens. The present method of research, however, permits of a much easier decision in this respect on account of the occurrence of one of the strongest groups of the whole spectrum of chromium, viz., λ4289.9, 4274.9, 4254.5 just within the part here photographed. It is not very difficult to find them out among the crowd of titanium lines on the photographs, and from their estimated intensities, to form at least an approximate idea of the greater or less quantity of chromium contained in the specimens examined. In the following table the results of these comparisons are given :

TABLE B.

RUTILE FROM

Chromium λ	I	Krageröe	Langöe	Lofteshagen	Käringbricka	Tachowaja	Miask	Binnenthal	Yrieix	Freiberg	Castilia	Graves Mountain	Arkansas
4254.49	6	tr.	3	3	2.3	3	tr.	...	2.3	2.3	2.3	2.3	...
74.91	6	...	2.3	2.3	2	2+	...	...	2	2	2	2+	...
89.87	6	...	2	2	2—	2	...	...	1.2	2—	2—	2	...

It will be seen that in different rutiles the chromium lines show differences of intensity, fully justifying the conclusion of a corresponding disparity in the amounts of the metal. Thus, while the Anatas and also the Arkansas rutile are absolutely free from chromium, and in the rutiles from Krageröe and Miask only a feeble trace is present, the other specimens contain a very considerable percentage of this metal. But the

most peculiar feature in this respect appears upon comparing chromium with vanadium. It is thus found that in those varieties of rutile which contain vanadium in any very appreciable amount, chromium is also present, while a small percentage of the former metal is accompanied by a corresponding scarcity or even complete absence of the latter.

In conclusion it should be remarked that in the case of the Norwegian rutile from Langöe the preceding results have been completely confirmed by ordinary chemical analyses kindly undertaken by Baron Nordenskiöld. It is thus evident that the accepted chemical analyses of the present mineral by no means possess the completeness or accuracy which the usual chemical methods are capable of giving.

STOCKHOLM ACADEMY OF SCIENCES,
April 1897.

TABLES OF THE PRACTICAL RESOLVING POWER OF SPECTROSCOPES.

By F. L. O. Wadsworth.

In the article "On the Conditions of Maximum Efficiency in the Use of the Spectrograph" published in a recent number of this Journal[1] I have pointed out that the commonly accepted formula for purity is incorrect and have derived (from theoretical considerations verified by experimental results) three new formulæ for the following cases which cover, I believe, all those met with in theory or practice:

1. The resolving power p (theoretical) for a wide slit and monochromatic radiations.

2. The resolving power R (limiting) for an infinitely narrow slit but for lines of finite width, $\Delta\lambda$.

3. The resolving power P (practical) for a wide slit and non-monochromatic radiations ranging for each line over a small value $\Delta\lambda$ as in (2).

The formulæ obtained were

$$p = \frac{\lambda}{s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda} r \tag{1}$$

$$R = \frac{\lambda}{\frac{1}{4} r\Delta\lambda + \frac{\lambda}{r\Delta\lambda + \lambda}\lambda} r \tag{2}$$

$$P = \frac{\lambda}{s\psi + \frac{\lambda\left(\frac{r}{R}\right)}{2s\psi + \lambda\left(\frac{r}{R}\right)}\left(\frac{r}{R}\right)} r \tag{3}$$

In these formulæ s is the width (linear) of the slit; ψ the the angular magnitude of the collimator as viewed from the slit; and r the theoretical resolution of the instrument for infinitely narrow slit and infinitely narrow spectral lines. The value

[1] "The Modern Spectroscope." *Ap. J.*, 3, 321, May 1896.

of r (which was first derived for both prisms and gratings by Rayleigh) may be most simply expressed as I have previously shown[1] as a product of the linear aperture, a, times the angular dispersion, D, divided by a constant m which varies from unity (for a rectangular aperture) to about 1.1 (for a circular aperture),

or $$r = \frac{Da}{m}$$

"a perfectly general relation which holds good whatever may be the nature, form or arrangement of the spectroscope train."

Since the above paper was published I have prepared tables giving the values of R, p, and P for values of r ranging from 25,000 to 1,000,000, values of $\Delta\lambda$ from 0.01 to 1.00 tenth-meters ($0^{mm}.000000001$ to $0^{mm}.0000001$) and values of $s\,\psi$ from 0.0005 to 0.020 ($s = 0^{mm}.005$ to $0^{mm}.3$, $\psi = \frac{1}{40}$ to $\frac{1}{10}$). All values are computed for $\lambda = 5500$ tenth-meters, that being the mean wave-length for the brightest part of the visible spectrum.

EXPLANATION OF THE TABLES AND REMARKS.[2]

An inspection of (1) shows that instead of diminishing continuously with increased slit width the purity of the spectrum first actually increases up to the point

$$s\,\psi \simeq \tfrac{1}{5}\lambda.$$

For, as may be easily proved, the expression for p becomes a maximum when

$$s\,\psi = \frac{\lambda}{2\,(1 + \sqrt{2})} \simeq \tfrac{1}{5}\lambda. \qquad (4)$$

Two close lines in the spectrum are therefore *more easily resolved when the slit has the small finite width given by* (4) *than when it is infinitely narrow*. This increased resolving power is due to the same effect as is produced by stopping out the central portion of the spectroscope aperture, *i. e.*, by a strengthening of the center of the diffraction image of the slit relatively to the

[1] "General Considerations respecting the Design of Astronomical Spectroscope," *Ap. J.*, **1**, 52, January 1895.

[2] See also recent paper by the writer "On the Resolving Power of Telescopes and Spectroscopes for Lines of Finite Width," *Phil. Mag.*, **43**, 317, May 1897, and *Mem. Spettr. Ital.*, **26**, 1, Jan. 1897.

edges. When the slit is wider than indicated by (4) (as it generally must be in order to obtain sufficiently bright spectra), the purity is diminished. To find the point at which it is equal to the theoretical resolution r we put

$$s\psi + \frac{\lambda^2}{2s\psi + \lambda} = \lambda$$

which gives at once

$$s\psi = 0 \text{ or } s\psi = \tfrac{1}{2}\lambda$$

or the theoretical purity is *still equal to the theoretical resolving power when the slit width is two and one-half times that required for maximum purity.*

Since the expressions for R (2) and P (3) are similar in form to that for p (1) just considered the same conclusions will hold. In the case of R the maximum value is attained when

$$r\Delta\lambda = \frac{1.5\,\lambda}{\sqrt{7} + 2} \cong \tfrac{1}{3}\lambda.$$

and the value of R is again equal to r when

$$r\Delta\lambda = \tfrac{3}{4}\lambda.$$

Hence for small values of either r or $\Delta\lambda$ the limiting resolving power will be greater than the theoretical resolving power of the instrument. But for any given value of $\Delta\lambda$ the value of R increases asymptotically with r towards a certain limit R_{max} which will evidently be

$$R_{max} = \frac{\lambda}{\frac{4}{7}\Delta\lambda} = 1.75\frac{\lambda}{\Delta\lambda}$$

or the maximum limiting resolving power of any instrument cannot be greater than one and three-quarter times the ratio between the mean wave-length and "width" of the spectral lines under examination.[1]

Our knowledge of the width of spectral lines under different conditions is at present very limited. Various hypotheses, of which the most noted are those of Lommel, Jauman, Galitzin, and Michelson, have been advanced to account for the broaden-

[1] This is on the assumption (see previous paper) that the distribution in intensity in the spectral lines follows the exponential law (Maxwell). As will be presently seen we can attain a somewhat greater practical purity P than this.

ing of the lines under varying conditions of temperature and pressure, and to give us a numerical measure of the amount, but they are all more or less unsatisfactory. Michelson's recent experimental work with the interferometer has given us our most exact knowledge of the widths of some few bright lines in the spark spectra of some of the metals under different pressures. In each case the exponential law of distribution is assumed, and the quantity given is δ, the "half width," which was defined in the preceding paper. It has been assumed as before that the effective range of wave-length $\Delta\lambda$ is about 4δ.

Table I contains a brief summary of some of the results obtained :

TABLE I.

Substance	Line λ	Character of source	Pressure in mm.	δ tenth-meters	$\Delta\lambda = 4\delta$
Hydrogen	$H\alpha$* 6565	Vacuum tube	Very low	.047	$\Delta\lambda = 0.328$*
	" "	" "	50	.098	$\Delta\lambda = 0.532$*
	" "	" "	100	.134	$\Delta\lambda = 0.696$*
	" "	" "	200	.230	$\Delta\lambda = 1.06$ *
Sodium	D_1* 5890	Vacuum tube	Very low	.005	0.020
	Not stated	Not stated	100	.09	0.30†
	" "	" "	200	.16	0.64†
	D_1* 5890	Bunsen flame	atmospheric	.05‡	0.27*
Cadmium	Red 6439	Vacuum tube, temp. about 280	Very low	.0005	0.026
	Green 5086	Vacuum tube, temp. about 280	" "	.0050	0.020
	Not stated	Not stated, probably spark	100	.05	0.200†
	" "	Not stated, probably spark	200	.08	0.32†
	" "	Not stated, probably spark	400	.14	0.56
Mercury	Green 5461	Vacuum tube, temp. about 100	Very low	.003‡	0.012

NOTES TO TABLE I.

* The red hydrogen line is a double, the distance between the components being about 0.14 tenth meters. The value given for δ is for each component, and the total effective width of the double line is therefore $\Delta\lambda = 4\delta + 0.14$. The same is true of

each of the D lines (according to Michelson each is made up of at least four components), the distance between the centers of the principal components being 0.07. When the density is low these components are therefore separated by much more than their own width, but when it is high (as in the Bunsen flame) each component broadens and overlaps the other so that the total effective width is as in the case of the H line $\Delta\lambda = 4\delta = 0.07$.

† There would seem to be some discrepancy between these results, which are given in the ASTROPHYSICAL JOURNAL for November 1895, p. 251, and the results previously obtained with the vacuum tube—(*Phil. Mag.*, September 1892, p. 280).

‡ Calculated from data given in *Phil. Mag.*, September 1892, p. 280.

The values of R, R_{max}, and $\frac{r}{R_1}$ for different values of r and $\Delta\lambda$, are given in Table II:

The vertical columns show the increase in the value of R with an increase in $\Delta\lambda$ for a given value of r; the horizontal lines show the increase in R with r for a given width of line. The last column gives the maximum resolving power R_{max} that can be obtained when the lines have the width $\Delta\lambda$ given in the first column.

We see that in general we will very nearly reach this limit when the theoretical resolving power r is about twice R_{max}. The additional gain in R obtained by further increase in r would not be worth the expense of the larger instruments required and the sacrifice in brightness necessary. Indeed, in most cases it would hardly be advisable to use a value of r greater than one to one and one-half times R_{max}, as with this we will have already attained from $\frac{3}{4}$ to $\frac{7}{8}$ of the limiting resolving power. The finest lines so far found (see Table I) have a width $\Delta\lambda$ of not less than 0.01 tenth-meter. For this width the value of R_{max} is 950,000, and the maximum theoretical power which it would be advisable to use would therefore be about 1,400,000, corresponding in the case of a grating[1] to an aperture of from 18 to 20 inches. On the other hand, for some of the wider lines, such as those of hydrogen in the vacuum tube and of many bright metallic lines in arc-spectra, there would be no advantage whatever in using

[1] See paper "Further Notes on Astronomical Spectroscopes," *Ap. J.*, 3, 180, March 1896; also "Resolving Power of Spectroscopes for Lines of Finite Width;" *Phil. Mag.*, May 1897.

TABLE II.

λ 5500 tenth-meters.

Δλ tenth meters.	r = [illegible]		r = 50,000		r = 100,000		r = 200,000		r = 500,000		r = 1,000,000		R_{max}
	r R	R	r R	R	r R	R	r R	R	r R	R	r R	R	
0.01	0.98	25,400	0.97	51,600	0.95	105,600	0.94	212,800	1.04	480,000	1.39	722,000	962,000
0.02	0.97	25,800	0.95	52,800	0.94	106,400	1.00	200,000	1.39	361,000	2.29	437,000	481,000
0.04	0.95	26,400	0.94	53,200	1.00	100,000	1.24	161,700	2.29	219,000	4.27	234,000	240,000
0.06	0.94	26,600	0.96	52,400	1.10	90,900	1.56	128,500	3.27	153,000	6.30	159,000	160,000
0.08	0.94	26,600	1.00	50,000	1.24	80,800	1.91	104,600	4.27	117,000	8.35	120,000	120,000
0.10	0.95	26,400	1.04	48,000	1.39	71,900	2.29	87,300	5.28	95,000	10.41	96,000	96,000
0.12	0.96	26,200	1.10	45,500	1.56	64,300	2.67	75,000	6.30	79,400	12.50	80,000	80,000
0.14	0.97	25,800	1.16	42,900	1.73	57,700	3.00	65,000	7.33	68,000	14.50	69,000	69,000
0.16	1.00	25,000	1.24	40,400	1.91	52,300	3.40	58,000	8.35	60,000	16.60	60,000	60,000
0.18	1.02	24,600	1.31	38,100	2.10	47,700	3.86	52,000	9.38	53,000	18.70	53,000	53,000
0.20	1.04	24,000	1.39	36,000	2.29	43,700	4.27	46,800	10.41	48,000	20.75	48,000	48,000
0.25	1.12	22,400	1.60	31,200	2.77	36,100	5.28	37,900	13.00	38,000	25.9	38,000	38,000
0.30	1.20	20,800	1.85	27,000	3.27	30,600	6.30	31,800	15.60	32,000	31.1	32,000	32,000
0.35	1.29	19,300	2.05	24,400	3.76	26,600	7.33	27,000	18.17	27,000	36.3	27,000	27,000
0.40	1.39	18,000	2.29	21,800	4.27	23,400	8.35	24,000	20.75	24,000	41.4	24,000	24,000
0.50	1.60	15,600	2.77	18,000	5.28	18,900	10.41	19,000	25.90	19,000	51.8	19,000	19,000
0.60	1.82	13,700	3.27	15,300	6.30	15,900	12.47	16,000	31.1	16,000	62.2	16,000	16,000
0.80	2.29	10,900	4.27	11,700	8.35	12,000	16.61	12,000	41.4	12,000	82.9	12,000	12,000
1.00	2.77	9,000	5.28	9,500	10.41	9,600	20.75	9,600	51.8	9,600	103.6	9,600	9,600

a resolving power greater than 20,000 to 25,000, for which a grating of $\frac{1}{2}$ inch aperture, or 5, 60° prisms of $1\frac{1}{4}$ inches aperture would suffice. For solar spectrum work in which the lines are not likely to be narrower than $\frac{1}{20}$ tenth-meter,[1] our present 5 and 6-inch gratings will do nearly all that we could hope to attain with larger apertures,[2] unless indeed there should be some marked advantage in particular cases in the use of the first and second orders of spectra, rather than the higher orders.

The preceding conclusions are all based on the assumption that the maximum practical resolving power r_0, which has been assumed to be equal to $1.5\frac{b}{\lambda}$ and which corresponds to an angle of deviation of about 90° ($\theta - i = 45°$ to $50°$), can be utilized. When for any reason this is not the case, whether because of the inaccuracies of ruling, the faintness of the higher orders of spectra, or the character of the mounting, a corresponding larger aperture must be made use of. If, for example, we consider the maximum angle of deflection to be 60° (which, from purely mechanical considerations, is about the largest possible angle that can be used in the ordinary Rowland mounting), we have for r_0

$$r = \frac{7}{8}\frac{b}{\lambda}.$$

In order to attain the same resolving powers R as before the apertures must be increased about 75 per cent. If we assume a maximum angle of 45°, which in practice is not often exceeded in our present gratings, the apertures would have to be increased by over 100 per cent., and we should therefore need to attain the full limiting resolving power R_{max}.

For lines $\Delta\lambda = .01$ tenth-meter, an aperture of at least 1^m.

For lines $\Delta\lambda = .02$ tenth-meter, an aperture of at least 50^{cm}.

[1] In the case of faint lines the apparent width may sometimes be less than this, because of the rapid falling off in intensity towards the edges of the line. For this reason estimates of pressure based upon the apparent visual widening of lines may sometimes be greatly in error.

[2] The latter would, however, be advantageous in giving increased accuracy and increased photographic resolution by reason of the greater linear dispersion. See *Ap. J.*, **1**, 233, and **2**, 264.

For lines $\Delta\lambda = .05$ tenth-meter (solar work), an aperture of at least 25^{cm}.

By an inspection of Table II it will be seen that while for narrow lines and small resolving power the ratio $\frac{r}{R}$ is very nearly unity and that formula (1) therefore represents very closely the purity of the spectrum, the same is by no means true for wide lines and large resolving powers. In the extreme case figured in the table the value of this ratio rises as high as 100. In order to show more clearly the influence of this factor on the purity of the spectrum under different conditions, Table III has been prepared, showing the values of P for different slit apertures, from $0^{mm}.005$ to $0^{mm}.3$, different widths of lines from 0.01 to 1.00 tenth-meters and resolving powers varying from $r = 25,000$ to $r = 1,000,000$. For comparison the values of p are given for each slit width and resolving power, and also the value p' calculated from the old formula for purity.[1] An inspection of the table shows at once how greatly in error estimates of purity based upon this old formula may be in some very common cases. Take for example the case of a spectroscope having a resolving power of 200,000 (5-inch grating, 20,000 lines, second order), working with an angular slit-width such that $s\psi = .005$ ($s = \frac{1}{50}{}^{mm}$, $\psi = \frac{1}{40}$, as in the concave grating). The value of p (1) is about 158,000, while the value of P varies from 163,000 to 10,000. The value of p' (old formula for purity) for the same case is only 105,000. It is, therefore, in this case, from 50 to 1000 per cent. in error. In case of larger resolving powers ($r = 1,000,000$) it may be as much as sixty times too great. In general, of course, the large values of $\Delta\lambda$ that give rise to the smaller values of P will not be used for visual work as there is, as already indicated, but little gain in practical resolving power or purity when the value of r is greater than the value of R_m given in Table II. But in photographic work it is, as already has been shown in a previous paper, a great advantage to use (for extended sources) a short camera and a very high resolving

[1] See article "Spectroscopy," *Enc. Brit.*, 22.

TABLE III.

$\lambda = 5500$ tenth-meters.

s	ψ radians	$s\psi$		w 4δ	r 25000	r 50000	r 100000	r 200000	r 500000	r 1000000
				.01	20000	40200	81200	163200	389000	662000
.005	$\frac{1}{10}$			.05	20300	40600	77800	132400	194000	207000
			P	.10	20300	38900	66200	91400	103400	102200
.010	$\frac{1}{20}$	0.0005		.50	15100	19400	20700	20400	19900	19900
				1.00	9700	10300	10200	10000	9800	9700
.020	$\frac{1}{40}$		p		19800	39600	79100	158200	396000	791000
			p		13100	26200	52400	104800	262000	524000
				.01	12400	24800	49700	99400	243000	454000
				.05	12400	24800	48700	90900	166000	202000
.010	$\frac{1}{10}$		P	.10	12400	24400	45500	74300	101500	108000
		0.001		.50	10900	16600	20200	21500	20400	19900
.015	$\frac{1}{15}$			1.00	8300	10100	10800	10300	10000	9800
			p		12300	24600	49100	98200	245000	491000
			p′		8900	17800	35500	71000	177000	355000
				.01	6700	13400	26700	53500	133000	259000
				.05	6700	13400	26600	51900	113600	171000
.020	$\frac{1}{10}$		P	.10	6700	13300	25900	47800	85700	103000
		0.002		.50	6400	11400	17100	20600	21000	20600
.030	$\frac{1}{15}$			1.00	5700	8500	10300	10600	10300	10000
			p		6650	13350	26700	53400	133500	267000
			p′		5400	10800	21600	43200	108000	216000
				.01	4500	9100	18100	36200	90200	178000
				.05	4500	9100	18000	35600	83100	141000
.030	$\frac{1}{10}$		P	.10	4500	9000	17800	34200	75700	95300
		0.003		.50	4400	8300	14100	19100	21100	20800
.045	$\frac{1}{15}$			1.00	4200	7600	9500	10500	10400	10100
			p		4500	9100	18100	36200	90500	181000
			p		3900	7800	15500	31000	77500	155000
				.01	2700	5400	10900	21800	54500	108000
				.05	2700	5400	10900	21800	52900	97300
.050	$\frac{1}{10}$		P	.10	2700	5400	10800	21400	48800	77100
		0.005		.50	2700	5300	9700	15400	20600	21100
.075	$\frac{1}{15}$			1.00	2600	4900	7700	9900	10500	10300
			p		2700	5400	10900	21800	54500	109000
			p′		2500	5000	9900	19800	49500	99000
				.01	1400	2800	5500	11000	27500	54900
				.05	1400	2800	5500	11000	27200	53000
.10	$\frac{1}{10}$		P	.10	1400	2800	5500	10900	26500	48800
		0.010		.50	1400	2700	5300	9800	17300	20600
.15	$\frac{1}{15}$			1.00	1400	2600	4900	7800	10300	10500
			p		1400	2800	5500	11000	27500	55000
			p′		1300	2600	5200	10400	26000	52000
				.01	700	1400	2800	5600	14000	27500
				.05	700	1400	2800	5500	13700	27200
.20	$\frac{1}{10}$		P	.10	700	1400	2800	5500	13600	26500
		0.020		.50	700	1400	2700	5300	11600	17300
.30	$\frac{1}{15}$			1.00	700	1400	2600	4900	8600	10300
			p		700	1400	2800	5600	14000	28000
			p′		650	1300	2600	5200	13000	26000

power, in order to attain a given degree of photographic purity. Another point which is of considerable practical importance in this connection is that for these large values of $\frac{r}{R}$ the purity of the spectrum may be maintained constant or even actually improved over a wide range of those slit widths actually used in practice. For the maximum value of P (as of p) will be attained when

$$s \simeq \tfrac{1}{5} \frac{r}{R} \lambda.$$

For $r = 200{,}000$, $\Delta\lambda = 1.00$, $\frac{r}{R} = 20.75$, and the maximum value of P is therefore attained when the value of $s\psi$ is about 4.15λ, or about .0023, corresponding for the usual spectroscope to a slit width of about $\frac{1}{30}^{\mathrm{mm}}$. Under the same circumstances the practical purity is still as great when the slit width is $\frac{1}{13}^{\mathrm{mm}}$ as when it is zero. For still higher resolving powers the maximum allowable widths of slit are still greater. Even with such low values of $\frac{r}{R}$ as 2 or 3 (corresponding to lines as fine as those sometimes found in the solar chromosphere, *i. e.*, 0.2 to 0.25 tenth-meter), and resolving powers of only 100,000, the purity remains undiminished up to values of $s\psi = \lambda$ to 1.5λ, (.0005 to .0008), or to slit widths (with the concave grating) of from $\frac{1}{50}$ to $\frac{1}{30}^{\mathrm{mm}}$.

YERKES OBSERVATORY,
February 1897.

THE NINETY FOOT DOME OF THE YERKES OBSERVATORY, AUGUST 22, 1896.

ERECTING THE CENTRAL GIRDERS.

PLATE III.

THE NINETY-FOOT DOME OF THE YERKES OBSERVATORY, AUGUST

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

IV. THE FORTY-INCH TELESCOPE, DOME AND RISING-FLOOR.[1]

By George E. Hale.

THE great tower which contains the forty-inch telescope of the Yerkes Observatory is at the western extremity of the main building. It is entered from the long corridor by means of a broad marble stairway, the upper landing of which is level with the rising-floor when the latter is at its lowest position. Two balconies encircle the inner wall of the tower. The upper one leads through doors at the cardinal points, to an outer balcony from which any part of the sky can be seen. The rising-floor is at this level when raised to its highest position. Twenty-three feet below, at the other limit of the floor's motion, is the second inner balcony. An iron stairway, following the curve of the wall, connects the balconies with each other and with the ground floor of the tower.

For the important purpose of ventilating the observing room the tower wall is pierced with thirty-two windows, arranged in three rows. These are intended to be kept open the greater part of the time, except when observations are being made. As a further means of maintaining the temperature of the interior closely on a par with that of the outer air, the doors leading from the body of the building are made double, and additional precautions are taken against the admission of hot or cold air.

The wall terminates at a height of fifty-two feet from the ground in a heavy stone coping, to which is anchored the circular track of T rails upon which the dome revolves.

[1] For previous articles in this series see the March, April, and May numbers of the Astrophysical Journal.

THE DOME.[1]

The great dome, like the rising-floor and the mounting of the forty-inch telescope, was designed and constructed by Messrs. Warner & Swasey, of Cleveland, Ohio, the well-known builders of the mounting of the Lick telescope. It is ninety feet in diameter, sixty feet high and weighs 140 tons. The construction of the steel framework will be easily understood from an inspection of the accompanying plates, which are reproductions of photographs taken while the dome was in process of erection. Two very heavy girders (Plate II) stand on either side of the observing slit and form the nucleus of the structure. They are carried by eight wheels, two at either end of each girder. The remainder of the framework is built up of smaller girders, bolted to the great central pair, and tied together with horizontal members. Plate III, from a photograph taken just as one of the small girders was being hoisted into place, shows how each of these members, with a wheel bolted to its lower extremity, was built into the ring which forms the base of the dome. After the various parts of the steel framework had been put in place, they were fastened together with hot rivets. A sheathing of wood (Plate V) was then fitted to the framework, and this in turn was covered with roofing tin. This wood covering is very advantageous in completely doing away with a difficulty commonly experienced under certain atmospheric conditions with all-metal domes, viz., the condensation of water, which drops upon the instrument and floor.

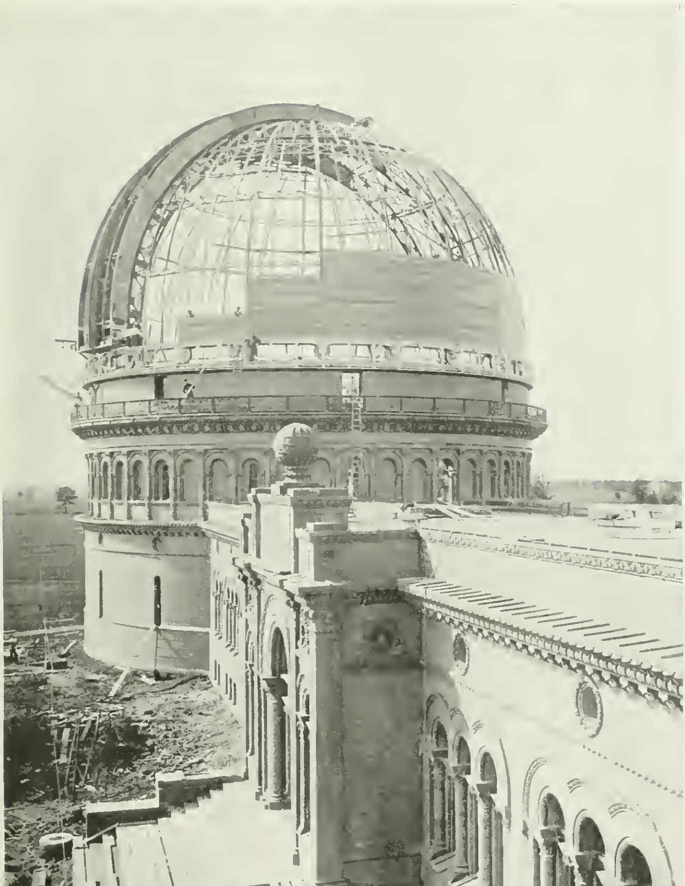
The thirty-six wheels upon which the dome revolves are each 36 inches in diameter. The journals, provided with roller bearings, are so mounted that the wheels are left free to adapt themselves to any possible inequalities of the track. The dome is revolved by means of an endless cable driven by an electric motor connected with the turning mechanism. Provision is also made for moving the dome by hand from the rising-floor or balconies.

The observing slit, thirteen feet wide, extends from the hori-

[1] For many of the details embodied in the following description of the dome, rising floor, and telescope mounting I am indebted to Messrs. Warner & Swasey

THE NINETY FOOT DOME OF THE YERKES OBSERVATORY, SEPTEMBER 9, 1896.

PLATE V



SHEATHING THE NINETY-FOOT DOME OF THE YERKES OBSERVATORY, OCTOBER 2, 1896.

zon to a point five feet beyond the zenith. The two shutters which cover this opening are eighty-five feet long. Roller-bearing wheels attached to the upper and lower ends of each shutter move on tangential tracks attached to the dome. The mechanism for operating them is so arranged that the two shutters move simultaneously from the center outward, remaining parallel to each other in all positions.

Within these shutters two canvas curtains, stretched across the opening, are mounted on tracks extending from below the horizon to a point about 50° beyond the zenith. These may be adjusted so as to shelter the telescope from the wind, in whatever direction it may be pointing. By this simple means, which is also used at the Nice and Meudon Observatories, it is expected that one of the greatest difficulties experienced in observational work with great telescopes will be in large degree overcome.

THE RISING-FLOOR.

The problem of providing suitable means of rendering accessible the eye-end of an equatorially mounted telescope, for all positions of the instrument, was happily solved by the invention of the rising-floor. When the Lick telescope was in process of construction, and the difficulty of observing objects at widely different altitudes with a telescope of such great focal length had been carefully considered, it was suggested by Sir Howard Grubb that the entire floor of the observing room be arranged to rise and fall. In this way the telescope would be equally available for observation at all altitudes. The plan was adopted at the Lick Observatory, and has since been used at the new United States Naval Observatory and at one or two smaller observatories abroad.

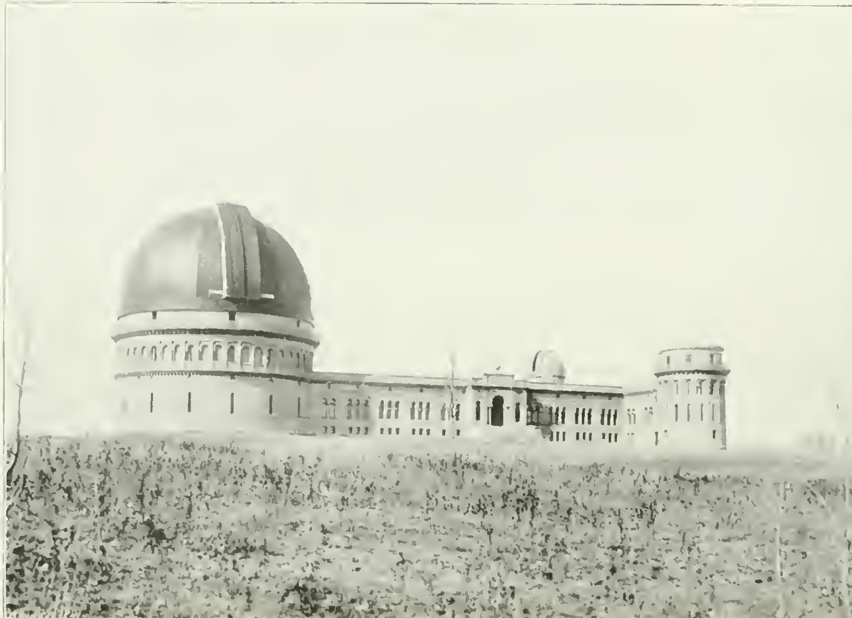
At the Yerkes Observatory the need for such a rising-floor was greater than at any other existing institution. Not only is the focal length (62 feet) of the large telescope greater than that of other equatorial refractors, but it was felt that provision should be made for attaching proportionally large spectroscopes. At the Lick Observatory the floor has a range of motion of 16

feet, and is moved by hydraulic rams. To provide sufficient room for a solar spectroscope (9 feet long) for use with the forty-inch telescope, it was found that the rising floor of the Yerkes Observatory must be 75 feet in diameter, and have a vertical motion of 23 feet. Hydraulic rams could not be used, on account of the danger of freezing in the severe cold of Wisconsin winters.

The rising-floor designed by Messrs. Warner & Swasey seems to meet these conditions in a satisfactory manner. The steel construction is much lighter, though not less rigid, than that of the Lick floor, and the total weight is $37\frac{1}{2}$ tons. Instead of the hydraulic rams used elsewhere, four pairs of wire cables 90° apart, support the floor. These pass over large sheaves and are attached at their opposite ends to counter-balance weights moving on guides in four steel columns. At the base of each column is a drum four feet in diameter, around which is wound a wire cable fastened to the lower side of the floor. The other end of this cable is attached to the bottom of the counterweights. Each drum has on its circumference a large worm gear, and the worm which drives it is carried on a shaft geared to the three other shafts that drive the corresponding drums. The four shafts are operated from a single point by means of an electric motor, which is controlled from a switch box on the rising-floor. By simply moving a switch the astronomer can thus bring the floor to any desired level. When the telescope is pointed to the zenith the objective is about 73 feet above the lowest position of the floor.

THE FORTY-INCH YERKES TELESCOPE.

Representing as it does an increase in aperture of but four inches over the largest equatorial refractor hitherto constructed, the Yerkes telescope might not at first sight be supposed to offer any special difficulties of construction or design. As a matter of fact, however, the problem of designing a suitable mounting for the forty-inch objective was by no means a simple one. The great weight of the objective (about 1000 pounds in



SOUTH FRONT OF THE YERKES OBSERVATORY.

PLATE VII.

ERECTING THE IRON COLUMN OF THE YERKES TELESCOPE, SEPTEMBER 8, 1896.

its cell) and the desirability of attaching an equally heavy spectroscope at the eye end made necessary the construction of a tube of exceptional rigidity. The consequent great weight of the moving parts must inevitably increase the difficulty of moving the telescope, and for this and other reasons it was decided to provide a complete system of electric motors and clamps, for the purpose of effecting the various operations usually performed by hand. It will thus be seen that the greatest experience and skill would be required of the designer of a really successful mounting.

After carefully examining most of the great telescopes in American and European observatories, the writer decided to recommend to Mr. Yerkes that the contract for the mounting be awarded to Messrs. Warner & Swasey, not only because of the well-known excellence of their workmanship, but more especially on account of the invaluable experience gained by this firm in designing and constructing the mounting of the thirty-six inch Lick refractor.

The frontispiece shows the Yerkes telescope as it appeared on May 11, 1897, when Messrs. Warner & Swasey's work had been practically completed. The cast-iron column (Plate VII) consists of four sections, tapering from 11 feet × 5 feet at the base to 10 feet × 5 feet at the junction with the head. These four sections are bolted together, and rest on a cast-iron foot 18 feet × 14 feet which is firmly anchored to a massive brick pier supported on a concrete foundation 32 feet × 28 feet × 5 feet. At the top of the column is the equatorial head, which is cast in a single piece. The column and head rise to a height of 43 feet above the lowest position of the rising-floor, and weigh 50 tons. Surrounding the head is an iron balcony, accessible from the rising-floor by means of a spiral stairway on the south side of the column, which also leads to the clock room in the upper section of the head.

The polar and declination axes are of hard forged steel, and weigh 3½ and 1½ tons respectively. The polar axis (Plate VIII), 13½ feet long, has a diameter of 15 inches at the upper

bearing and 12 inches at the lower bearing. At both of these points the friction is relieved by means of live rings of steel rolls, running in steel yokes, and held against the axis by spring levers. The lower end of the axis rests on a double set of forty hardened steel balls, one inch in diameter. The upper end carries the main driving gear, which has 330 teeth, is 8 feet in diameter, and weighs one ton. This is driven by a worm geared to the driving clock, and when clamped to the axis sets in motion a mass weighing 20 tons.

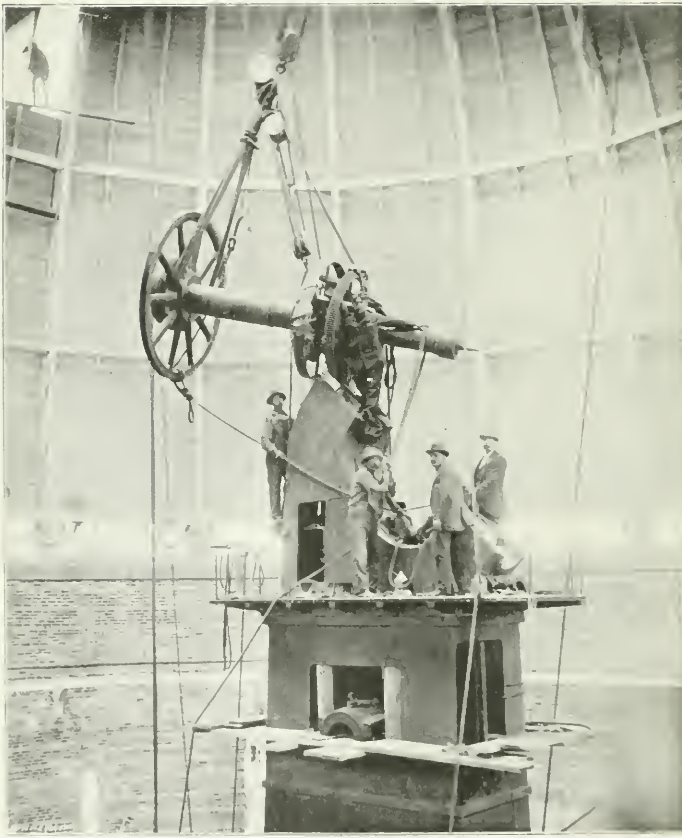
The declination axis (Plate IX) which runs in Babbitt bearings in the declination sleeve, is 12 inches in diameter and 11½ feet long. The pressure of this axis upon its bearings, amounting, with the weight of the tube, to about 8 tons, is relieved by a live ring of steel rolls, which greatly reduces the friction.

The tube is made of sheet steel, varying in thickness from $\frac{7}{32}$ inch at the center to $\frac{1}{8}$ inch at the ends. Its diameter is 52 inches at the center, 42 inches at the objective end and 38 inches at the eye end. It is 60 feet long, and weighs 6 tons. For the central section, to which the declination axis is bolted, it was considered necessary to use some material more reliable than cast-iron, which is ordinarily employed in smaller mountings. The heavy sheet steel selected for this purpose seems to be in all respects satisfactory.

The driving clock stands in the clock room (Plate X) in the upper section of the column, where it is easily reached from the spiral stairway. It is of the type used by Messrs. Warner & Swasey in all of their mountings, with additional change gears for mean solar and lunar rates. The double conical pendulum, mounted isochronously on the well-known plan long ago suggested by Professor Young, makes sixty revolutions per minute. It is provided with a simple electric control, similar in principle to the control applied by Professor Keeler to the driving clock of the Lick telescope. An electric motor automatically winds the clock when the driving weight has reached a point near the limit of its run.

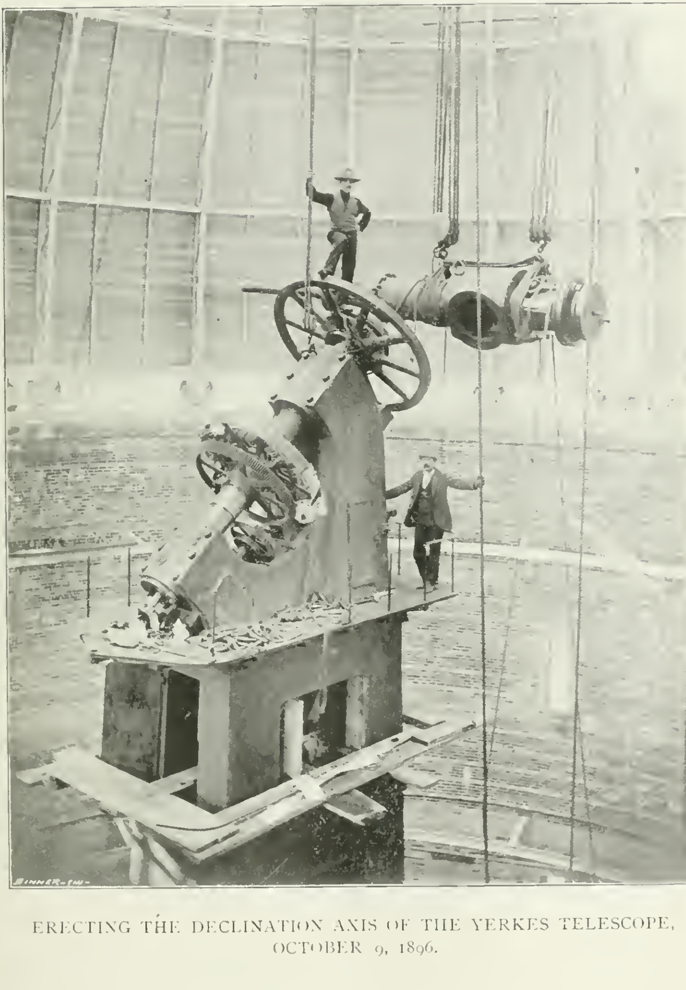
The telescope is so designed that it is in perfect balance

PLATE VIII.



ERECTING THE POLAR AXIS OF THE YERKES TELESCOPE, OCTOBER 8, 1896.

PLATE IX.



ERECTING THE DECLINATION AXIS OF THE YERKES TELESCOPE, OCTOBER 9, 1896.

with a spectroscope weighing about half a ton attached to the eye end. When the spectroscope is removed iron weights are clamped to the tube near the eye end in order to restore the balance.

The clamps and slow motions can be operated by the observer at the eye end, where the fine declination circle can also be read. An assistant on the balcony can move the telescope in both right ascension and declination, and read the fine hour circle. The divisions of the coarse circles are visible from the floor.

In addition to the ordinary appliances just referred to for actuating the quick and slow motions and clamping the telescope, a complete system of electric motions, clamps and illumination is also provided. It is rather surprising that so convenient a means of operating a large telescope, first suggested by Sir Howard Grubb, and strongly commended by Dr. Gill, has not hitherto been adopted. Conveniently placed switches at the eye end and on the equatorial head, enable the observer or his assistant on the balcony to start or stop the slow motion motors, and to clamp or unclamp in right ascension and declination, by simply pressing knobs. The quick motion motors (shown in Plate XI) are controlled from the balcony and eye end by switches. The circles are illuminated by incandescent lamps, connected with switches at the eye end and on the head. Provision is also made for electric illumination of the micrometer wires.

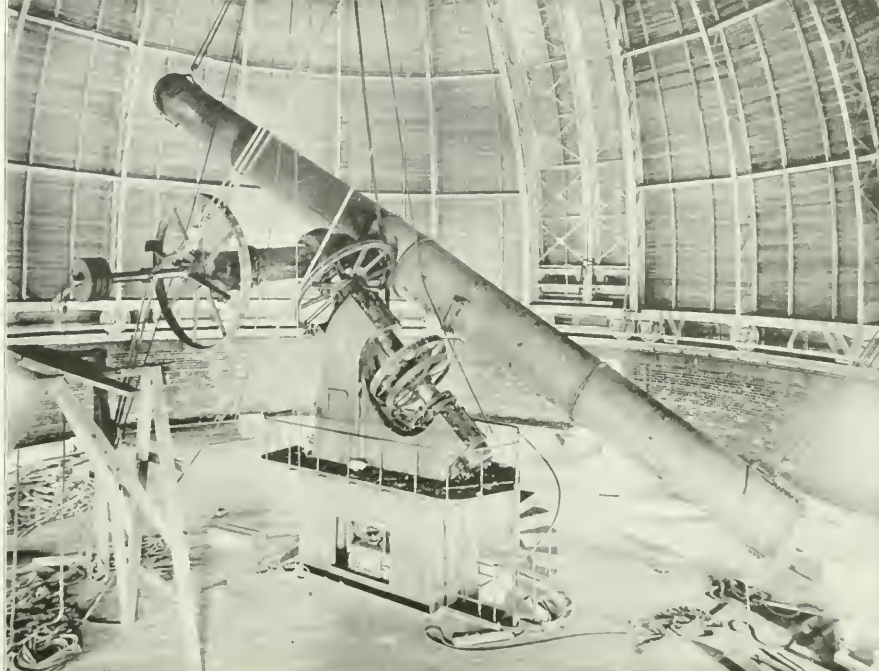
The forty-inch objective of the Yerkes telescope was made by the firm of Alvan Clark & Sons from disks furnished by Mantois of Paris.[1] The crown lens is about 2½ inches thick at the center and ¾ of an inch at the edge; it weighs 200 pounds. The flint lens, which is separated from the crown by a distance of 8⅜ inches, is about 1½ inches thick at the center, 2 inches thick at the edge, and weighs over 300 pounds. The lenses are mounted upon aluminium bearings in a cast-iron cell. The focal length of the objective is very nearly 62 feet.

[1] An account of the manufacture of these disks, illustrated with reproductions of photographs of the rough glass blocks, is given by Mr. J. A. Brashear in *Popular Astronomy*, 1, February 1894.

The terms of the contract between Mr. Yerkes and Messrs. Alvan Clark & Sons required that the objective be examined by an "expert agent" before acceptance. At the request of the writer, Professor James E. Keeler kindly made the necessary tests at Cambridgeport in October 1895. Profesor Keeler's report has already been published in the ASTROPHYSICAL JOURNAL (4, 154, February 1896). After certain changes had been made in the position of the lenses in the cell, he found that "the expanded star disk was round inside and outside of the focus, uniformly illuminated, and free from wings or other appendages. Good images at the focus were obtained of stars at widely different altitudes near the meridian, the definition being in my opinion, with due allowance for atmospheric disturbance, equal to that of the Lick telescope, while the brightness of the image was of course considerably greater than with the latter instrument." . . . . "The absence of ghosts and the small amount of diffuse light when this brilliant star (Sirius) was in the field were particularly noted. The color correction of the forty-inch objective is, according to my best recollection, almost precisely the same as that of the Lick objective." The writer was led to similar conclusions from independent tests made on the same occasion.

ACCESSORIES OF THE FORTY-INCH TELESCOPE.

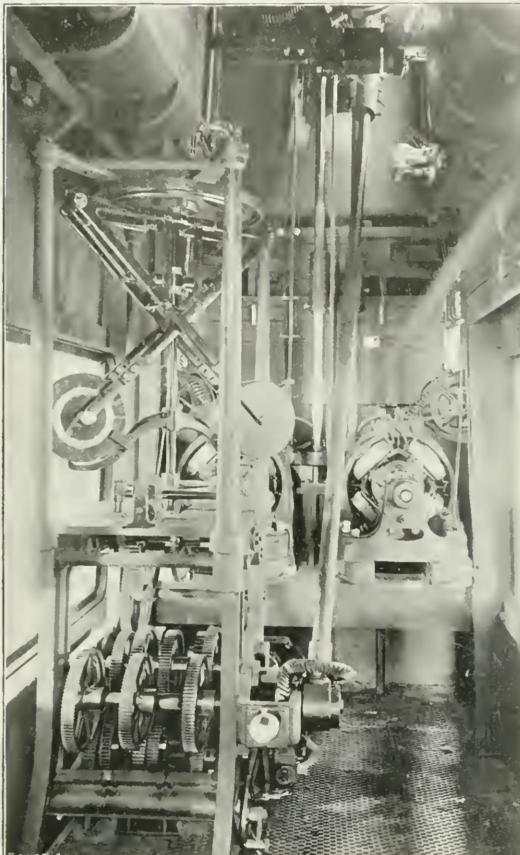
Micrometer.—The filar micrometer shown in Plate XI was designed and constructed by Messrs. Warner & Swasey, after suggestions by Professor Burnham. In its general form and details it is similar to the micrometer of the 36-inch at Mt. Hamilton, which has proved so satisfactory in the measurement of all kinds of difficult objects. The eyepieces were made by Steinheil & Sons, of Munich; they are of the latest and best form for micrometrical work, and give powers ranging from 150 to about 3000. The micrometer is furnished with Burnham's illuminating device giving bright wires on a dark field. Provision is also made for illuminating the wires electrically. The amount of light on the wires can be instantly changed by the



MOUNTING OF THE FORTY-INCH YERKES TELESCOPE, NOVEMBER 1896.

THE RISING FLOOR IS SHOWN AT ITS HIGHEST LEVEL.

PLATE XI.



CLOCK ROOM OF THE YERKES TELESCOPE.

observer so as to adapt the illumination to the measurement of the faintest objects which the telescope will show.

Solar spectroscope and spectroheliograph.—The combined solar spectroscope and spectroheliograph at present used with the Yerkes telescope is the instrument designed by the writer in 1889, and used in his work at the Harvard and Kenwood Observatories.[1] It has recently been remodeled in the instrument shop of the Yerkes Observatory, the lever system and moving slits formerly used being replaced by a moving collimator slit and plate of the type designed by Professor Wadsworth.[2] On account of the comparatively small angular aperture of the collimator and camera objectives, this spectroheliograph is not well adapted for use with the forty-inch telescope. The solar image at the focus of the telescope is nearly seven inches in diameter, and of this a zone only two inches wide and three inches long can be photographed in a single operation. It will therefore be necessary to obtain a larger spectroheliograph as soon as possible.

As a solar spectroscope and spectrograph the old instrument has long since demonstrated its excellence. With collimator and telescope objectives of three and one-quarter inches aperture and forty-two and one-half inches focus, and a four-inch Rowland grating having 14,438 lines to the inch,[3] the spectroscope may fairly be accounted a powerful one. Various investigations have been planned, however, which require a much higher photographic resolving power, and a larger spectroscope will be required to meet these needs.

Stellar spectrograph.—The great light-gathering power of the forty-inch telescope particularly adapts it for investigating stellar spectra. For this purpose an excellent stellar spectrograph, designed and constructed by Brashear, has been presented to the Observatory by Mr. Yerkes. This instrument is in almost

[1] An illustrated description of this instrument is given in *Astronomy and Astro-physics* **11**, 407, 1893.

[2] This JOURNAL **1**, 244, March 1895.

[3] A five-inch grating with 20,000 lines to the inch is also available for use with this spectroscope.

every respect similar to the spectrograph built by Brashear after Professor Keeler's indications for the Allegheny Observatory.[1] The collimator and camera objectives are of 1¼ inches aperture and nineteen inches focal length. A train of three flint prisms is ordinarily employed for photographic work, but in addition to these, single light and heavy flint prisms, and a Rowland grating, with long and short observing telescopes and a filar micrometer, are provided for visual observations. The collimator has a range of motion of five inches, on account of the special color curve of the forty-inch telescope. A correcting lens for photographic work in the upper spectrum will be furnished by Brashear. The slit is made with polished jaws of speculum metal, on the plan devised by Dr. Huggins. By observing with a small telescope the image reflected from the slit jaws, the task of finding a faint star or of holding the slit during an exposure upon some chosen region of a planet or other extended object, is greatly simplified. The spectrograph is provided with all necessary apparatus for producing comparison spectra. It is in every respect a very complete and satisfactory instrument.

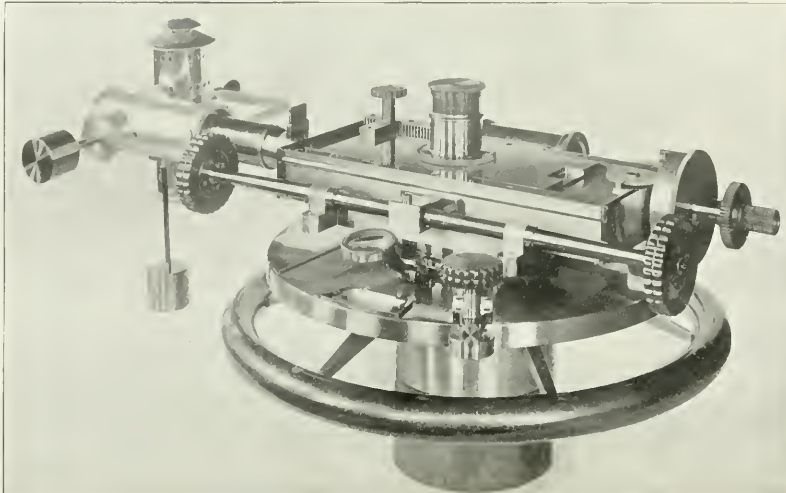
Arrangements have been made for attaching various other instruments to the eye end of the forty-inch telescope, including bolometric apparatus for experiments on the solar corona, and the twelve-inch photographic objective of the small equatorial, for use in connection with the solar work.

In the present series of articles the writer has endeavored to give some account of the material equipment of the Yerkes Observatory.[2] The forty-inch objective has recently been put in place, and the adjustments of the large telescope are being made Of the detailed plans for the investigations to be undertaken by Professors Burnham, Barnard, Wadsworth, and the writer with this and other instruments, it is unnecessary now to speak. It

[1] See *Astronomy and Astrophysics* 12, 40, 1893.

[2] For a full statement regarding the admission of advanced students to the Yerkes Observatory see the *Annual Register* of The University of Chicago.

PLATE XII.



FILAR MICROMETER OF THE YERKES TELESCOPE.

may be said, however, that if the ideas of the present members of the staff are maintained, the work is not likely to partake of that element of sensationalism which threatens to disfigure modern observational astronomy.[1]

YERKES OBSERVATORY,
May 1897.

[1] The excellent photographs used in illustrating these articles have been made, with one or two exceptions, by Mr. Ferdinand Ellerman, Assistant in the Yerkes Observatory.

RADIATION IN A MAGNETIC FIELD.

By Albert A. Michelson.

In the interesting and important paper of Zeeman on the influence of magnetism on the nature of the light emitted by a substance[1] there is a reference to the work of the late M. Fievez,[2] who found that instead of a broadening of the spectral lines, there were reversals and double reversals which Zeeman has not observed.

In some cases the magnitudes to be observed are of the order of a fortieth of the distance between the sodium lines, and should be clearly seen in a good spectroscope under proper conditions; but others occur in which they are but a third or a fourth as large, and in these cases all detail is lost in diffraction effects and optical imperfections.

For the investigation of just such cases the *interferometer* is particularly adapted, and it was determined to investigate the problem with the aid of this instrument.

The first substance tried was sodium. A bead of sodic carbonate was placed in the flame of a small hand blowpipe, which could be kept under better control than a Bunsen burner. This was placed between the flat pole-pieces of a moderately large electro-magnet in the manner described by Zeeman, and the light after passing through a collimating lens entered the interferometer. The difference of path commencing at zero was increased by single turns of the millimeter screw, noting at each turn, the clearness or visibility of the interference fringes, first without and then with the magnetizing current.

The curves *A* and *D*, Fig. 1,[3] show the results of this experiment. They are the envelopes of the visibility curves, the alternations of which are too rapid to show on this scale. The

[1] *Phil. Mag.*, March 1897; this Journal, May 1897.

[2] *Phil. Mag.*, September 1892.

[3] Negative ordinates indicate reversal of the fringes.

abscissae are differences in path of the interfering pencils in millimeters. From these the distribution of light in the source

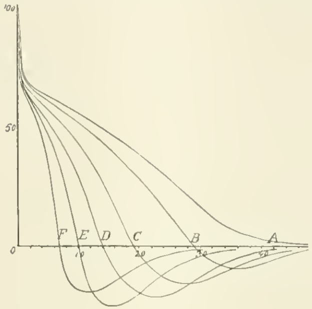


FIG. 1.

is found as described in a previous article.[1] The results are shown at A and D, Fig. 2, the first representing the appearance

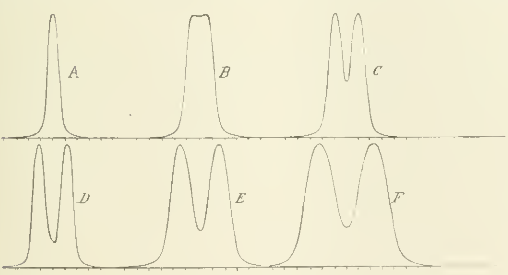


FIG. 2.

of one of the sodium lines without, and the second with the magnetizing current.

It is evident from the figures that the broadening of the line is relatively insignificant, but that it is separated into two com-

[1] *Phil. Mag.*, September 1892.

ponents of equal intensity.[1] The question at once arises whether or not this fact lends support to the conclusion of Fievez, that the effect of a magnetic field is to produce reversals. The appearance of the figure itself seems to indicate a true separation, the depression bearing a much larger proportion to the whole area than we are accustomed to observe in reversals; but this by itself would hardly be considered conclusive. It was thought, however, that if there were a true separation, the distance between the components should vary with the strength of the field, whereas in the case of a reversal one would expect only an increase in the darkness of the absorption.

Accordingly a series of observations was made with varying strength of field, the results of which are shown in the visibility curves of Fig. 1, and the corresponding intensity curves of Fig. 2. The strength of field, in the order of the letters was 0, 5, 7, 11, 16, 20. It appears from the figures that up to a strength of field 11, which is about 2000 C. G. S., the principal effect is a doubling of the line; but beyond this, the component lines are broadened as well as separated. It is also clear that the separation is nearly proportional to the strength of field. Thus, assuming this law to be true, the following table shows the agreement between the observed and the calculated distances.

F = strength of field; Δ = difference of path in millimeters corresponding to visibility 50 for single source; δ = the corresponding half width of the source on a scale of 100 for $D_1 - D_2$; D = the period of the coincidences in millimeters due to the doubling; and a = the corresponding distance between the components.

TABLE I.

	F	Δ	δ	D	a	a calc.
A	0	20	.66	∞	0.0	0.0
B	5	20	.66	58	1.0	1.0
C	7	20	.66	38	1.6	1.5
D	11	20	.66	28	2.2	2.3
E	16	14	.94	18	3.3	3.4
F	20	10	1.32	14	4.3	4.2

[1] A triple line would give a totally different visibility curve.

The next substance examined was cadmium. Cadmium filings were enclosed in an end-on vacuum tube which was placed between the poles of the electro-magnet. The results are

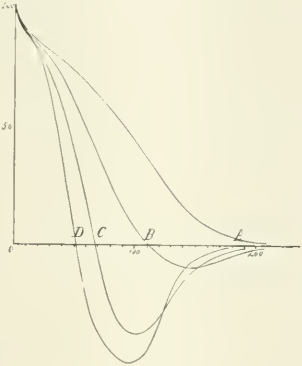


FIG. 3.

shown in Figs. 3 and 4, and prove that there is scarcely any broadening of the red cadmium line with the magnetic fields used. The doubling is even more pronounced than in the case

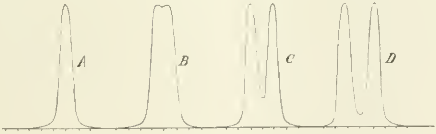


FIG. 4.

of sodium, and the following table (page 52) shows that the distance between the components is proportional to the strength of field.

The results with cadmium are therefore essentially the same as with sodium, and are perhaps even more convincing from the

TABLE II.

	F	Δ	δ	D	[illegible]	[illegible] calc.
A	[illegible]	90	.15	∞	.00	.00
B	4	90	.15	220	.27	.28
C	6	90	.15	136	.44	.42
D	[illegible]	90	.15	102	.59	.63

fact that the red cadmium line is almost ideally simple. Further, the fact that the same results are obtained under such very different conditions (metallic cadmium vapor in a vacuum tube

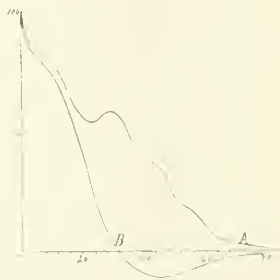


Fig. 5.

as against sodic carbonate in a blowpipe flame) would seem to furnish additional evidence against the reversal hypothesis.

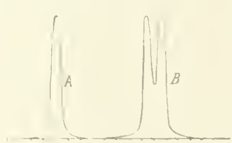


Fig. 6.

The light from sodium in a vacuum tube has a somewhat complicated and variable structure, but in one experiment, the result of which is given in Fig. 5, the visibility curve (envelope)

is relatively simple, and the corresponding intensity curves, Fig. 6, show results almost identical with *A* and *B*, Fig. 2. The strength of the magnetic field was approximately the same in the two cases.

The green cadmium line, however, is both separated and broadened, and the blue line more than the green. The green

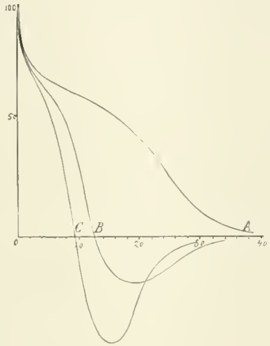


FIG. 7.

line of mercury is rather interesting on account of its complicated structure, and the results show that the general effect of the magnetic field is to obliterate details of structure, changing the form to a simple doublet, as in the other cases. The separation and the broadening are nearly the same as for the green cadmium line.

Hydrogen in a vacuum tube and lithium and thallium in the blowpipe flame are but little affected. These lines are all originally double, and in all three cases the only effect observed in the magnetic field is a slight broadening and a slight increase in the distance between the components.

In all the preceding experiments the light was examined in a direction at right angles with the magnetic field. When sodium light was allowed to pass through cylindrical holes in the pole-

pieces, so that the pencil was parallel with the field, the same effect of separation of the line into two was observed, and was even more clearly marked than in the transverse direction, but the broadening was inappreciable. This appears from an inspection of Figs. 7 and 8.

The fact that broadening occurs only or chiefly when the pencil of light is at right angles with the field, may possibly be

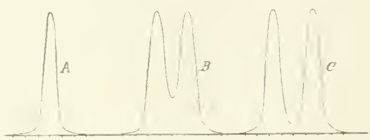


FIG. 8.

accounted for by an increase of velocity of the radiating atom in this direction. This is what should be expected if the atom is electrified and in motion; for then a velocity at right angles with the original one would be added, giving a resultant velocity greater than before. The effect of this increased velocity would be a displacement of the corresponding spectral line proportional to the component of the velocity in the line of sight due to the Doppler effect; and as the increased velocity occurs only in the equatorial plane the broadening would be observed chiefly in this plane.[1]

According to Zeeman the only effect of the magnetic field is to broaden the spectral lines, and the theoretical investigation fails to account for the doubling which has been observed in almost every case thus far examined.

[1] It is worth noting that in almost every instance the magnetic field caused a perceptible increase in brightness.

Minor Contributions and Notes.

ON THE MODE OF PRINTING MAPS OF SPECTRA AND TABLES OF WAVE-LENGTHS.

To the opinions previously expressed in the Astrophysical Journal regarding the best mode of printing maps of spectra and tables of wave-lengths, we are now able to add the following statements:

"I see that you invite opinions as to the direction in wave-length of the printing of maps and tables of spectra. I regard the two cases as distinct. I am strongly of opinion that any change in the direction of maps from the classical one, now further sanctioned by Rowland's great solar map, in which the red is opposite the right hand, would be little less than intolerable in practice. I hope that you will regard the question, in respect of maps, as one that cannot be reopened. The case of tables is different. I think that Rowland's tables are in the wrong direction, and that the classical direction of placing the largest wave-lengths at the top of the tables should be adopted. This would agree with Professor Kayser's view."

William Huggins.

"I notice that you ask for expressions of opinion in regard to the best mode of printing maps of spectra.

"My vote is for the present decision of the Astrophysical Journal, placing the origin of wave-lengths on the left, and this for the following reasons:

"1. The diffraction grating is now and will probably continue to be our principal means of studying spectra under high magnification, and while it is of course possible to use a grating either right or left in observing, we should naturally plot our measurements on the wave-length scale, which is the one given by direct observation with a Rowland's apparatus. If we adopt the λ scale, we should also expect to use the common convention of mathematicians in curve-tracing, allowing its positive numerical value to increase on the right hand.

"2. We must lay our plans for probable future growth, and here it seems to me that there is great hope of development in the infra-

red region, which in extent far exceeds all the rest of the spectrum, and which also includes the larger part of the radiant energy in all but the emanations from the hottest sources. Instead of compressing the infra-red into a small space, which must be done if the frequency scale is used, it is desirable to leave room for indefinite extension in this direction.

"3. The sequence of numerical properties in the frequencies of vibration for certain substances might be urged as one reason for adopting a frequency scale, and placing this with its zero on the left, were it not that there are sequences running in either direction, and thus there is no particular reason why we should adopt a different order from that of direct wave-length measurement unless we propose to give up all order, and let each investigator please himself in this matter.

"But (4) if it is a good thing to have an established order, it should be selected on the principle of conducing to the greatest use: and here it seems to me, while admitting the existence of good arguments on the opposite side, the chief use of the order in question is to aid the memory in recalling the disposition of a host of objects. But with this purpose in view it makes less difference what the order is than it does to have it include the chief examples to which we must continually recur. The majority of the most important publications in this line place the violet end of the spectrum on the left. It is therefore well to continue the practice.

"If the question be argued much farther, we shall land in metaphysics; but it might be pointed out that since time is measured by change of position of bodies in space, our foundation should be laid in space (λ) rather than in time $\left(\frac{1}{\lambda}\right)$.

"I prefer the micron as the unit of wave-length since its size is commensurate with the thing to be measured, and it seems to be the natural unit for microscopists. It is time enough to consider millimicrons ($\mu\mu$) when we get to chemical molecules, and the tenth-meter is yet farther away from our object (the measurement of wave-length) involving, in the case of an imperfectly known λ, the addition of one or more insignificant ciphers, which is misleading, or else requiring the adoption of a makeshift such as the colon (:) or dash (—) in place of unknown final figures, as in Frost's Scheiner."

FRANK W. VERY.

NOTE.

As Mr. Jewell's letter in the April number of this JOURNAL might imply to those who have not read Dr. Arendt's article in *Wiedemann's Annalen* that the reviewer of the article had introduced errors into it, the words in question of the reviewer are here repeated, together with the extracts from Dr. Arendt's paper upon which they were based.

This JOURNAL (5 : 153): "To calculate the corrections it was necessary to test the law of increase of intensity of the lines with increase of path, which from observations of Cornu and of Müller was expected to be that of direct proportionality. This was fully confirmed by series of observations on the same day at different solar altitudes."

Wied. Ann. (58 : 191): "Aus diesen Angaben lässt sich leicht ein Correctionsglied bestimmen, sofern nur der gesetzmässige Zusammenhang zwischen Weglänge und Stufenwerth der Linien bekannt ist. Nach Cornu und Müller soll die Zunahme der Linienintensität der Vergrösserung des Luftweges direct proportional sein. Bei der Bedeutung, welche dieses Gesetz im vorliegenden Falle besitzt, schien es mir wichtig, dasselbe noch einmal eingehend zu prüfen ; zu dem Zwecke wurde eine Anzahl von Beobachtungsreihen bei dem verschiedensten Sonnenstande mit dem schon früher erwähnten kleineren Spectralapparate ausgeführt."

Page 192 : "In übersichtlicher Weise kann man durch Anwendung des graphischen Verfahrens ein Bild von dem Zusammenhange zwischen Linienintensität und Weglänge gewinnen, indem man in ein rechtwinkliges Liniensystem die vom Lichtstrahle durchlaufenen Wegstrecken in der Luft als Abscissen und die entsprechenden Stufenwerthe der Linien als Ordinaten einträgt ; die Verbindungslinie der Endpunkte der letzteren nähert sich einer Geraden." Later (p. 196) Arendt refers to the "in der Tabelle *C* geführten Nachweis von der Proportionalität zwischen Weglänge und Linienintensität."

Of course Mr. Jewell's more detailed reference to his own observations is preferable to the necessarily brief allusion to them in the review, where it was only remarked that "The procedure adopted by Dr. Arendt appears as suitable, and the results obtained as satisfactory as those described by Jewell in a late number of this JOURNAL (4, 324–342), where a photographed scale was employed for comparisons of intensity."

EDWIN B. FROST.

DEDICATION OF THE YERKES OBSERVATORY.

The formal dedication of the Yerkes Observatory will take place on October 1, 1897. Although the details of the programme have not yet been arranged, it is considered desirable to give early announcement of the date. It is hoped that European men of science who purpose to attend the Toronto meeting of the British Association for the Advancement of Science, in August, may think it desirable to take part in the formal inauguration of the Yerkes Observatory. In connection with the dedicatory exercises it is planned to hold a series of informal conferences on astronomical and astrophysical subjects. The fourth annual meeting of the Board of Editors of the Astrophysical Journal will also occur at the same time. A cordial invitation is hereby extended to all men of science who may be willing to honor the Observatory by their presence on this occasion.

George E. Hale.

ERRATA.

The following corrections should be made in the Rev. J. Fényi's article "Prominences Observed on August 8, 1896" in this Journal, 4, 263, November 1896.

Page 263, line 9, for $22^h\ 40^m$ read $21^h\ 40^m$.

In the table $+29$ should be added to the heliographic latitudes of all prominences on the east limb, and -29 to the latitudes of those on the west limb.

For the words *Heliogr. Long.* at the head of the third column of the table substitute *Heliogr. Lat.*

The drawings reproduced in Plates VII and VIII are correct.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. The Sun.

Hills, E. H. Total Solar Eclipses. M. N. **57**, 282–284, 1897.

Maier, M. Sonnenbeobachtungen für das Jahr 1896. A. N. **143**, 95, 1897.

Mellor, T. K. The Nuclei of a Sun-spot. M. N. **57**, 406–407, 1897.

Porter, T. C. and others. Observations taken at Vadsö during the total eclipse of the Sun, 1896, Aug. 9. M. N. **57**, 414–419, 1897.

3. Stars and Stellar Photometry.

Barnard, E. E. Note on Professor Campbell's observations of Nova Aurigae. Ap. J. **5**, 277–278, 1897.

Campbell, W. W. Spectroscopic Notes. Ap. J. **5**, 233–243, 1897.

Dyson, F. W. The Astrographic Chart. M. N. **57**, 298–299, 1897.

Dyson, F. W. The Cape Photographic Durchmusterung. M. N. **57**, 297–298, 1897.

Evershed, J. Cause of the Darkness of Sun-spots. Ap. J. **5**, 244–253, 1897.

Hall, M. The Sidereal System, revised in 1896. M. N. **57**, 357–378, 1897.

Plummer, W. E. A photometric catalogue of the Southern Stars (Harvard). M. N. **57**, 294–296, 1897.

Stone, E. J. Estimations of the magnitude of Nova Aurigæ made at the Radcliffe Observatory. M. N. **57**, 401–402, 1897.

4. Stellar Spectra, Displacements of Lines and Motions in the Line of Sight.

Fowler, A. Chemistry of the Stars. Knowledge, **20**, 118, 1897.

LOCKYER, J. N. On the iron lines present in the hottest stars. A. N. **143**, 59–61, 1897.

PICKERING, EDWARD C. The Spectrum of Zeta Puppis. A. N. **142**, 399–401, 1897.

PICKERING, EDWARD C. Stars Having Peculiar Spectra. Ap. J. **5**, 350–353, 1897.

5. PLANETS, SATELLITES AND THEIR SPECTRA.

BARNARD, E. E. Physical and Micrometrical Observations of the Planet Venus, made at the Lick Observatory with the 12-inch and 36-inch Refractors. Ap. J. **5**, 299–304, 1897.

BRENNER, L. Veränderungen auf dem Mars 1896. A. N. **143**, 41–43, 1897.

CERULLI, V. Note su Marte. Dall' Ottobre 1896 al Gennaio 1897. A. N. **143**, 44–45, 1897.

EDITORS OF THE OBSERVATORY. The rotation periods of Venus and Mercury. Obs'y **20**, 172–173, 1897.

EDITORS OF THE OBSERVATORY. Recent Observations of Mars. Obs'y **20**, 132–134, 1897.

KEELER, JAMES E. Spectrographic Observations of Mars in 1896–7. Ap. J. **5**, 321–328, 1897.

LOWELL, P. Drawings of Mercury. A. N. **142**, 391, 1897.

LOWELL, P. Further proof of the rotation period of Venus. M. N. **57**, 402–405, 1897.

MARTH, A. Ephemerides for physical observations of Mercury. M. N. **57**, 426–430, 1897.

SCHIAPARELLI, M. and F. TERBY. Rotation de Vénus. Bull. Soc. Belge d'Astron. **2**, 146, 1897.

WILLIAMS, A. S. The past opposition of Mars. M. N. **57**, 284–286, 1897.

6. COMETS, METEORS AND THEIR SPECTRA.

ADAMS, J. C. On the orbit of the November meteors. M. N. **57**, 387–393, 1897.

DENNING, W. F. Progress of Meteoric Astronomy in 1896. M. N. **57**, 270–280, 1897.

FOOTE, WARREN M. A Meteorite from New Mexico. Nat. **55**, 572–573, 1897.

HOLETSCHEK, J. Bemerkungen und Berichtigungen zur Cometenliteratur. A. N. **143**, 113–121, 1897.

ROBERTS, I. Attempt to photograph the Leonids in open sky. M. N. **57**, 430–431, 1897.

7. NEBULÆ AND THEIR SPECTRA.

MAUNDER, E. WALTER. Nebula round η Argus. Knowledge, **20**, 120–122, 1897.

8. TERRESTRIAL PHYSICS.

JEWELL, LEWIS E. Dr. Arendt's Spectroscopic Investigation of the Variation of Aqueous Vapor in the Atmosphere. Ap. J. **5**, 279–282, 1897.

9. EXPERIMENTAL AND THEORETICAL PHYSICS.

PASCHEN, F. Ueber Gesetzmässigkeiten in den Spectren fester Körper. Wied. Ann. **60**, 662–723, 1897.

RUBENS, H. and A. TROWBRIDGE. Beitrag zur Kentniss der Dispersion und Absorption der ultrarothen Strahlen in Steinsalz und Sylvin. Wied. Ann. **60**, 724–739, 1897.

SCHMIDT, G. C. Polarisirte Fluorescenz. Wied. Ann. **60**, 740–754 1897.

STEWART, OSCAR M. On the Absorption of the Extraordinary Ray in Uniaxal Crystals. Phys. Rev. **4**, 433–457, 1897.

STONEY, G. JOHNSTONE. On a Supposed Proof of a Theorem in Wave-motion. Phil. Mag. **43**, 368–373, 1897.

SWINTON, A. A. C. Some Experiments with Kathode Rays. Nat. **55**, 568–571, 1897.

TROWBRIDGE, JOHN. Electrical Conductivity of the Ether. Am. Jour. Sci. (4) **3**, 387–390, 1897.

TROWBRIDGE, JOHN and THEODORE WM. RICHARDS. The Temperature and Ohmic Resistance of Gases during the Oscillatory Electric Discharge. Phil. Mag. **43**, 349–367, 1897.

WADSWORTH, F. L. O. On the Resolving Power of Telescopes and Spectroscopes for Lines of Finite Width. Phil. Mag. **43**, 317–343, 1897.

WAIDNER, C. W. Review of: Physical Properties of X-Rays. Ap. J. **5**, 282–290, 1897.

ZEEMAN, P. On the Influence of Magnetism on the Nature of Light emitted by a Substance. Ap. J. **5**, 332–347, 1897.

10. THE SPECTRA OF THE ELEMENTS.

BERTHELOT. Recherches sur l'hélium. Ann. Chim. et Phys. **11** (7), 15–27, 1897.

KAYSER, H. On the Spectrum of Hydrogen. Ap. J. **5**, 243, 1897.

12. INSTRUMENTS AND APPARATUS.

BERTHELOT. Nouvel appareil pour l'application de l'analyse spectrale a la reconnaissance des gaz. Ann. Chim. et Phys. **11** (7), 43–47. 1897; C. R. **124**, 525–528, 1897.

CHILD, C. D. and O. M. STEWART. Most Sensitive Arrangement of a Wheatstone Bridge with Special Reference to the Bolometer. Phys. Rev. **4**, 502–504, 1897.

LORD, H. C. Curvature of the Spectral Lines. Ap. J. **5**, 348–350 1897.

LORD, H. C. Notes on the Determination of the Focus of an Objective. Ap. J. **5**, 305–309, 1897.

LUCAS, R. P. Un interrupteur rapide au mercure de construction très simple. Bull. Soc. Belge d'Astron. **2**, 119–125, 1897.

TODD, DAVID P. Automatic Photography of the Corona. Ap. J. **5**, 318–324, 1897.

TURNER, H. H. On a Photographic Transit Circle. M. N. **57**, 349–356, 1897.

WADSWORTH, F. L. O. Application of the Interferometer to the Measurement of Small Angular Deflections of a Suspended System. Phys. Rev. **4**, 480–497, 1897.

WADSWORTH, F. L. O. Thermal Measurements with the Bolometer by the Zero Method. Ap. J. **5**, 268–276, 1897.

WOLF, MAX. Reflector and Portrait Lens in Celestial Photography. Nat. **55**, 582–586, 1897.

WRIGHT, W. H. A Method of Correcting the Curvature of Lines in the Spectroheliograph. Ap. J. **5**. 325–327, 1897.

13. GENERAL ARTICLES.

COMMON, A. A. Address on Presenting the Gold Medal to Professor E. E. Barnard. M. N. **57**, 321–328, 1897.

FAYE, H. Sur l'observatoire de l'Etna, d'après les observations de M. Riccò. C. R. **124**, 797–800, 1897.

Hale, George E. The Yerkes Observatory of The University of Chicago. II. The Building and Minor Instruments. Ap. J. **5**, 254–267, 1897.

Hale, George E. The Yerkes Observatory of The University of Chicago. III. The Instrument and Optical Shops, and the Power House. Ap. J. **5**, 310–317, 1897.

Schwarzschild, K. Zur Bestimmung der Theilungsfehler von Maastäben. A. N. **143**, 1–11, 1897.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.*

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME VI AUGUST 1897 NUMBER 2

ON THE LAW OF SPECTRAL SERIES.

By T. N. Thiele.

Having long been occupied with investigations on the law of spectral series, I am in a position to affirm that if this problem seems beyond the reach of mathematical *deduction*, it is certainly very difficult to obtain by *induction* a sufficiently approximate general solution by means of the measures of spectra which we possess at the present time. The first steps in this direction were relatively easy, but in order to develop ultimately what may be considered known at the present time regarding the simplest series and double or triple lines and series, it is necessary to study with great care the not infrequent small anomalies which prevent us from considering these ideas as other than very imperfect approximations. It is necessary also to investigate the very complex cases in which the deviations present themselves in great detail, and from which we may be able to obtain, though at the expense of great labor, new and important information. For this problem is a very troublesome one, and those who occupy themselves with it cannot hope to make, so far as my experience goes, those little discoveries which relieve tedious investigations. In fact, one's fundamental assumptions often give way before the constant criticism to which they are exposed.

The more or less complete resolution of spectra into series

may, however, be accomplished before the general law of series is discovered, and I desire to contribute in some small degree to this useful work. For the present I confine myself to a few general remarks, all of them, with perhaps a single exception, of a negative character.

The single established fact in the present theory of series, the only one which my investigations have more and more tended to confirm, is that the law which expresses the wave-length λ of the lines of a series as a function of the series-number n of the lines must have the form

$$\lambda = f\left[(n + c)^2\right], \qquad (1)$$

where c is a constant, which I shall call the phase of the series. Excepting certain developments in series which are evidently but slightly convergent, all the formulæ hitherto proposed are special cases of this general form. Taking this law as a fundamental hypothesis, I accept all its consequences, some of which seem to have been rather neglected up to the present time.

Giving n successively all real integral values, it is evident that λ must have at least one maximum and one minimum value, representing what are called the heads of the series. According to formula (1) there is an important difference between these values, which in reality exists, and which must be indicated by a suitable nomenclature. In the neighborhood of $\lambda_0 = f(0)$ a finite number of lines are united into an ordinary *head*, but near $\lambda_\infty = f(\infty)$ an infinite number of lines are generally crowded into a finite space. This last form clearly occurs in line spectra, and I propose to call λ_∞ the *tail* of the series.

The difference between band and line spectra may be expressed as follows: In band series we ordinarily observe the heads, while these are invisible in line series, either on account of their extreme position or because of the poverty of lines in these spectra. As regards the tails, I have already remarked that they are found in line spectra, but they have not been noticed in band spectra. One is tempted to consider this invisibility as a characteristic feature of band spectra; but I have

suspected the presence of certain discontinuities in one of M. Rydberg's photographs of the spectrum of cyanogen: certain sudden interruptions of the fogged gray background which might be regarded as the tails of the series in this spectrum, though it is impossible to refer each one to its series. This is unfortunate, for the presence of both the head and tail of the same series would probably greatly facilitate the discovery of the law of the series.

The most important consequence of our hypothesis, $\lambda = f\left[(n+c)^2\right]$, is that it is necessary to take into account not only the lines corresponding to positive values of n, but also those obtained when $n < 0$. In other words a series must in general be composed of two groups of lines, each of which would ordinarily be called a series. I prefer to put it that the positive branch of each series must be accompanied by a negative branch of the same series, having the same head and the same tail and being represented alternately by a line in each interval of the other branch. These two branches may exactly coincide, in which case the phase of the series must be either $c = 0$ or $c = \frac{1}{2}$ (evidently c must be defined so as to include only fractions properly so called).

That each series consists of two branches is not merely a logical consequence of the equation $\lambda = f\left[(n+c)^2\right]$: it is a well-established fact in many spectra, notably in the case of band spectra. Here the phenomenon is so regular that in cases where such double branches are not observed (*e. g.*, in the spectrum of nitrogen) it may be concluded that $c = 0$ or $c = \frac{1}{2}$ with great probability that this supposition will be confirmed by subsequent calculations.

However, it is not safe to assume that both branches of each series will invariably be seen. In certain instances, illustrated in the spectrum of carbon, the two branches are equally intense, with the maximum of intensity in the head. But in other spectra the intensity is distributed with much less equality and regularity. For example, the great series discovered by Professors Kayser and Runge in the third band of cyanogen has

another branch which is still more intense near the common head $\lambda_0 = 3883.55$; the intensity of this latter branch, however, falls off more rapidly than does that of Kayser and Runge's branch, so that it has totally disappeared at $n = 100$, while the first branch remains visible when n is nearly twice as great. Frequently the two branches are confused near the head, and when this duplicity has been resolved, the difference between the positive and negative series-numbers of the lines of the two branches may be great enough to account for the extreme faintness or invisibility of one of them. Although standing side by side, they belong to entirely different parts of the series.

Sometimes there are numerous branches. Instead of two, three or four or even more are found, none of which show coincidences of their ordinary lines. In such an embarrassment of riches it becomes necessary, in order to separate them from the others, to discover pairs of branches whose not very regular spacing seems to indicate that if sufficiently prolonged they would present coincidences other than those of the head or tail. It then becomes a question, not of the branches of a single series, but rather of two neighboring and parallel series, analogous to doublets in line spectra, although they do not obey the well-known criterion of the latter: $\frac{1}{\lambda_n} - \frac{1}{\lambda'_n} =$ const.

Line spectra also offer many examples of series having two branches. We may probably cite all the double series except the doublets properly so called, for example the double series of the alkalis. In the case of hydrogen the series discovered by Professor Pickering seems to be the negative branch of that which has been regarded as the sole and complete series of this element. Then for hydrogen the phase must be $c = \frac{1}{4}$, for in this way one of the branches comes by interpolation in the middle of the other's intervals, without that irregular progression generally presented by series, except the double series $c = 0$ and $c = \frac{1}{2}$, and particularly the series $c = \pm \frac{1}{4}$.

In line spectra we have even less reason than in the case of band spectra to expect the regular appearance of the two

branches. That they perhaps differ very decidedly in intensity or even in appearance is not at all surprising, for in line spectra they in reality belong to entirely different parts of the series. On the side of the tail they are separated by an infinitude of invisible lines; on the side of the head by a finite and even small number of lines, which, nevertheless, make a double passage across the invisible regions of the spectrum. Moreover, even in these spectra an analogous phenomenon has been remarked: the series of diffuse lines and those of sharp lines.

The question now arises whether the double series ordinarily found in metallic spectra may not also be regarded as constituting a single series. It is known that the tails of the members of the pairs coincide, but nothing is known regarding the heads; it may be supposed, however, that they also coincide, as the ordinary lines of these series are never coincident. In each interval of the series there is always found a single line belonging to the other; these apparently always occupy the same position in the interval, as must be the case if both series can be expressed by the same formula $\lambda = f\left[(n + c)^2\right]$, positive values of n referring to one series and negative values to the other.

While I do not wish to assert that these pairs of series are in reality merely branches of single series, I desire to point out that at the present time this is the most probable supposition, which should not be abandoned except in the face of the strongest arguments. For reasons already indicated it is clear that such arguments are not to be found in differences in the intensity and the appearance of the lines.

But if by chance there were to be discovered in the spectra of certain metals four corresponding branches, two of them sharp and the remaining two diffuse, the argument against the general connection of these pairs as branches of single series would be strengthened, especially if at that time our knowledge of the general law of series had so far advanced as to permit us to determine the phase of each branch independently. For until the nearly definitive discovery of the true law of series has been

made, I suppose the phase could be well determined only by indirect interpolation of the positions of the lines of one of the branches in the intervals of the other. Thus only a systematic variation in this progression of values of the phase can demonstrate in a satisfactory manner the non-correspondence of the two branches of the series.

In this JOURNAL (4, 369) Professor Pickering has used a formula for the series in which four arbitrary constants can be introduced. Its slightly modified algebraic form

$$\lambda = \frac{\lambda_0 a + \lambda_\infty (n+c)^2}{a + (n+c)^2} \qquad (2)$$

requires that $\lambda = \lambda_0$ when $n + c = 0$ and $\lambda = \lambda_\infty$ when $n = \infty$.

This formula is a generalization of Rydberg's formula, just as the latter is a generalization of Balmer's. It is evidently a special case of $\lambda = f\left[(n+c)^2\right]$. We may also write

$$\frac{\lambda - \lambda_0}{\lambda_\infty - \lambda} = \frac{(n+c)^2}{a} \quad \text{or} \quad \frac{\lambda^{-1} - \lambda_0^{-1}}{\lambda_\infty^{-1} - \lambda^{-1}} = \frac{\lambda_\infty}{\lambda_0} \frac{(n+c)^2}{a};$$

the algebraic form and three of the constants, viz., the phase, the head, and the tail, remain the same if in place of wave-lengths, λ, we prefer to employ wave-frequencies, λ^{-1}.

In these rather delicate investigations this formula is very useful. It possesses the great advantage of having easily determinable constants. If for four series-numbers m, n, p, and q, one of which is arbitrary, the wave-lengths M, N, P, and Q are known, we have, after eliminating three constants, the final equation

$$\frac{M-N}{M-P} \cdot \frac{P-Q}{N-Q} = \frac{(m+c)^2 - (n+c)^2}{(m+c)^2 - (p+c)^2} \cdot \frac{(p+c)^2 - (q+c)^2}{(n+c)^2 - (q+c)^2}$$

whence

$$(m+n+p+q+4c)^2 = (m-n+p-q)^2 + \frac{4(m-q)(n-p)}{1 - \frac{M-N}{M-P} \cdot \frac{P-Q}{N-Q} \cdot \frac{m-p}{m-n} \cdot \frac{n-q}{p-q}}.$$

Having found c by this formula or in some other way, we must first of all search for the value of λ_∞ corresponding to the

tail of the series, using three wave-lengths and the corresponding series-numbers. Thus we have

$$\frac{(p+c)^2-(m+c)^2}{N-\lambda_\infty}=\frac{(p+c)^2-(n+c)^2}{P-N}=\frac{(n+c)^2\,(m-+c)^2}{N-M}.$$

Analogous formulæ for λ_0 and a are not required; it is better to use at once the value of λ_∞ found in the transformation of the wave-lengths λ into $(\lambda-\lambda_\infty)^{-1}$, for

$$(\lambda-\lambda_\infty)^{-1}=\frac{a+(n+c)^2}{a\,(\lambda_0-\lambda_\infty)} \tag{3}$$

is a complete function of the second degree, from which the constants a and λ_0 (and c as a check), as well as the table of wave-lengths, are easily obtained by interpolation.

Unfortunately, as I in fact suspected a year ago, this formula is not the true law of series. When tested with many observed series which are long and rich in lines, it shows decided deviations of a fairly constant and systematic character. It invariably places the tail at too great a distance from the head and from the observed λ. The other constants are also unsatisfactorily determined by Professor Pickering's formula: in some cases of band series I have found errors in the phase amounting to several units. Nevertheless the usefulness of this formula is not confined to the recognition of lines in a new series. Its degree of approximation is nearly always sufficient to serve as a point of departure, and frequently the series are simple or short enough to be represented without sensible error by this remarkable formula.

For more precise investigations Professor Pickering's formula may be replaced by an algebraic series of which it represents only the first term. But the succeeding terms must be chosen in such a manner as to sacrifice none of the value of Professor Pickering's formula. If, for example, we were to substitute for $(\lambda-\lambda_\infty)^{-1}$ a complete function of $(n+c)^2$,

$$(\lambda-\lambda_\infty)^{-1}=a_0+a_1(n+c)^2+a_2(n+c)^4+a_3(n+c)^6+\ldots.$$

such a simple and convenient formula would in general be too slowly convergent. For the long series of band spectra it might

be very useful as far as the region of the tail, but for line spectra it is necessary that the function (3) shall remain of the second degree for large values of $(n + c)$.

A better form would be

$$\left.\begin{aligned}\lambda &= \lambda_\infty + \frac{a_1}{(n+c)^2 + C_1} + \frac{a_2}{(n+c)^2 + C_2} + \ldots \\ &\frac{p_0 + p_1(n+c)^2 + \ldots + p_r(n+c)^{2r}}{q_0 + q_1(n+c)^2 + \ldots + q_r(n+c)^{2r}}\end{aligned}\right\} \quad (4)$$

This formula, which like that of Professor Pickering has the same general form for λ and for λ^{-1}, is the only one that I can recommend. It is not very convenient, the principal difficulty being the determination of the phase c, which can be obtained only by hypothesis or by indirect interpolations. Subsequently λ, $\lambda(n+c)^2$, ... and $\lambda(n+c)^{2r}$ must be developed in complete functions of the common argument $(n+c)^2$ (*e. g.*, by Newton's general interpolation formula), and values of q_0, q_1, ... q_r must be found such that the sum

$$q_0\lambda + q_1\lambda(n+c)^2 + \ldots + q_r\lambda(n+c)^{2r}$$

shall not be of higher degree than the second. It further remains to develop this function, *i. e.*, $p_0 + p_1(n-c)^2 + \ldots + p_r(n+c)^{2r}$ and to compute a table of its values, or to solve the equation

$$0 = q_0 + q_1(n+c)^2 + \ldots + q_r(n+c)^{2r},$$

the roots of which are the constants $-C_1$, ... $-C_r$ of the first form of (4), and finally to compute its other constants, a_1, ... a_r.

In these computations it is necessary to employ good observations and to subject them to rigorous criticism by means of preliminary approximate computations. For small errors may frequently lead to a positive root such that a denominator $(n+c)^2 + C_r$ may pass through zero between two observed lines, in which case the whole computation would be compromised.

As an illustration of these operations, I return to the question of the relation between sharp and diffuse series as branches

of a single series. I have chosen as an example the admirable observations of Professors Runge and Paschen on the spectrum of helium,[1] and in particular the two series or branches of which the wave-lengths reduced to a vacuum are given in the second column of the following table.

n	λ	$L' = \sqrt{\frac{1}{\lambda - \lambda_\infty} - \frac{1}{\lambda_0 - \lambda_\infty}}$	ΔL	$L - L$	$c = \frac{L - L}{2 \Delta L}$
3	7067.61	.0238188		.0026253	.14884
3	5877.477	.0264441			
4	4714.668	.0326440	.0088209	26210	.14856
4	4472.878	.0352650			
5	4122.115	.0414774	88222	26098	.14790
5′	4027.457	.0440872			
6	3868.689	.0503064	88228	26036	.14754
6	3820.813	.0529100			
7	3734.045	.0591329	88224	25995	.14732
7′	3706.185	.0617324			
8	3653.140	.0679590	88216	25952	.14710
8	3635.408	.0705542			
9	3600.480	.0767782	88220	25980	.14724
9′	3588.430	.0793762			
10	3564.123	.085605	8815	2586	.1467
10	3555.590	.088191			
11	3537.954	.094425	8830	2596	.1470
11	3531.636	.097021			
12	3518.47	.103238	8835	2618	.1482
12	3513.63	.105856			
13	3503.45	.112115	8825	2565	.1453
13′	3499.76	.11468			
14	3491.75	.12095	8815	2545	.1444
14	3488.85	.123495			
15	3482.58	.12961	8825	2710	.1535
15′	3480.08	.13232			
			887		
16	3472.91	.14119			
			884		
17	3467.01	.15003			
			822		
18	3462.4	.15825			
			.00955		
19′	3457.9	.1678			

In the first column are given the series-number [illegible] to 19′ referring to the sharp series and 3 to 15 to the diffuse series. These series-numbers are identical with those of Professors Runge and Paschen and have been confirmed by preliminary

[1] This JOURNAL, 3. 4.

computations made with the aid of Professor Pickering's formula. I have reason to believe that they really represent the whole numbers which most closely correspond to the true values of $n + c$. With the values $\lambda_\infty = 3422$ and $\frac{1}{\lambda_0 - \lambda_\infty} = -.000292036$ obtained from a preliminary computation, I have calculated the third column $L' = \sqrt{\frac{1}{\lambda - \lambda_\infty} - \frac{1}{\lambda_0 - \lambda_\infty}}$, in such a manner that it would be a linear function $= a + \beta n$, if Professor Pickering's formula were exact for the sharp series. The fourth column, $\Delta L'$, containing the first differences of the third, shows how well founded this hypothesis is. The fifth column contains the differences of the third column for the same series-numbers 3 and 3′ . . . . 15 and 15′ of the two series (sharp and diffuse). Divided by twice the numbers corresponding to the fourth column $2\Delta L'$, these give us the values of the phase c which are found in the sixth column.

There is evidently an *approximate* constancy in these values of the phase; a conclusion based on the varying value of c that the two series are unrelated would not be justifiable. The slight variation indicated at the head of the sixth column is perhaps only a consequence of the approximate nature of our computation. To enable us to judge of this the degree of approximation must be carried to such a point that the two series, considered as branches of a single series, may be sufficiently well represented by the same formula, for example of the form (4).

For the value of the phase required in this computation, I started with $c = 0.147$, in the selection of which I was guided by the sixth column of the table. With this there resulted too great a difference between the computed and observed values corresponding to $n = 3$ and $n = 4$. For $n = 8$ . . . . $n = 15$ the agreement was satisfactory.

In a second computation, using the value $c = 0.150$, I found

$$\lambda = 3421.676 + \frac{13719.472}{(n + c)^2 - 4.385604} - \frac{632.574}{(n + c)^2 + 18.79675}.$$

The particular values of this function, with the differences between the observed and computed values, are given in the following table:

$n+c$	λ comp.	$o-c$	$n+c$	λ comp.	$o-c$
−14.85	3482.509	+ .07	3.15	5877.477	.000
−13.85	3491.868	.12	4.15	4472.868	+.010
−12.85	3503.590	− .14	5.15	4027.457	−.017
−11.85	3518.554	− .08	6.15	3820.813	.000
−10.85	3538.093	− .139	7.15	3706.176	+.009
− 9.85	3564.313	− .190	8.15	3635.404	+.004
− 8.85	3600.719	− .239	9.15	3588.432	−.002
− 7.85	3653.506	− .366	10.15	3555.574	+.016
− 6.85	3734.581	− .536	11.15	3531.636	−.009
− 5.85	3869.561	− .872	12.15	3513.656	−.03
− 4.85	4123.641	−1.526	13.15	3499.780	−.02
− 3.85	4717.376	−2.708	14.15	3488.844	+.01
− 2.85	7069.532	−1.92	15.15	3480.067	+.01
− 1.85	−10851.859		16.15	3472.914	.00
− 0.85	− 356.046		17.15	3467.006	.00
+ 0.15	+ 243.634		18.15	3462.068	+.3
+ 1.15	− 1088.710		19.15	3457.899	.0
+ 2.15	+61308.022				

The branch of the positive values of $n+c$ is thus very well represented by this formula, while the other branch only shows differences which are sufficiently small to permit us, by the use of $\frac{d\lambda}{dn} = \frac{d\lambda}{dc}$, to draw conclusions regarding the possibility of obtaining a better agreement by the use of some other hypothesis concerning c. The reply is in the negative: it is impossible to appreciably diminish these differences, taken as a whole, without subsequent complication of the formula. While the addition of a term $\frac{a}{(n+c)^2+C_3}$ would certainly cause the difference for $n+c=-2.85$ to disappear, and at the same time decrease the other differences, it may be seen that there would nevertheless remain a marked systematic deviation.

In spite of the remarkable correspondence of these two series, I must therefore deny their unity.

Both may be represented as having exactly coincident branches, *i. e.*, by the aid of formula (4) in which $c=0$ or $c=\frac{1}{2}$.

Or again, if we suppose that the two branches corresponding to negative values of n are too faint to be observed, they may be represented by Professor Pickering's formula, placing:

Sharp series	Diffuse series
$\lambda_\infty = 3421.967$	$\lambda_\infty = 3421.967$
$\lambda = 0.052$	$\lambda = 58.070$
$a = -3.757$	$a = -3.825$
$c = -0.001542$	$c = -0.28824$

THE OBSERVATORY, COPENHAGEN.
June 1897.

ON THE RELATIVE BEHAVIOR OF THE H AND K LINES OF THE SPECTRUM OF CALCIUM.[1]

By Sir William Huggins and Lady Huggins.

The remarkable relative behavior of the lines in the spectra of certain substances as they appear at and near the Sun's limb, and in the atmospheres of stars of different classes, has long been before our minds as a problem of great interest, which there is reason to believe is capable of solution by the methods of the laboratory, and on which we have worked from time to time for many years. Without waiting for the results of other researches which are in progress, we think that it is desirable to put on record some definite results on the behavior of the lines of calcium, which appear to us to be conclusive and of great importance in forming a correct interpretation of many solar and stellar phenomena.

As early as 1872 Professor Young from a few weeks' work at Sherman on the spectra of the chromosphere and of the prominences, was able to point out that "the selection of lines seems most capricious; one is taken and another is left, though belonging to the same element, of equal intensity, and close beside the first." Especially he noticed that while the H and K lines of calcium are almost always observable, the strong blue line as well as the other lines of this metal are very seldom seen. In his table of the chromospheric lines Professor Young gives for the frequency of this strong blue line the small number 3; while for the frequency of H and K he gives respectively the high numbers 75 and 50.

From 1863, when I mapped the spectrum of calcium with a strong spark from metallic calcium (*Phil. Trans.*, 1864, p. 139) I have constantly used the lines of calcium as a comparison spectrum in stellar work. The experience was familiar to me that as the quantity of calcium salt on the electrodes became very

[1] Read before the Royal Society.

small, H and K continued strong even when the other calcium lines had almost disappeared. The suggestion then occurred to me that this behavior of the lines might furnish a clue to the phenomena which take place near the Sun's limb.

We were encouraged to use this experience as a guiding thought in the experiments about to be described, by the consideration that in the higher solar regions, where H and K appeared alone of the calcium lines, the density must be much less than at the lower level of the reversing layer. It seemed very probable that in the simple fact of difference of density lay the true explanation of the modifications of the calcium spectrum as they are presented to us in solar and stellar phenomena.

The problem before us was, therefore, to find out by experiments in the laboratory, under what conditions the lines of calcium other than the lines H and K, and in particular the strong blue line at 4226.9, were so greatly enfeebled relatively to H and K, that they became quite insignificant, and if possible, disappeared altogether from the spectrum, leaving the very simple spectrum of the two lines H and K, or nearly so.

Professor Lockyer states that: "Some of the substances which have been investigated, including iron, calcium, and magnesium, have probably a definite spectrum, consisting of a few lines, which can only be completely produced at a temperature higher than any which is at present available in laboratory experiments." (*Proc. R. S.*, **61**, 205.)

In the case of calcium:

"(4) A spectrum consisting of the two lines at 3706.18 and 3737.08 and the H and K lines, corresponding to a temperature higher than the average temperature of the spark, as before explained." (*Ibid.*, p. 161.)

Such a spectrum was not actually obtained, but experiments with a large intensity coil suggested that by a still greater increase of intensity of the spark such a simple spectrum might appear. The intensity of the strong blue line was reduced to one half of H and K. (*Ibid.*, Table, p. 162.)

Kayser and Runge found 106 lines of the calcium spectrum

to belong to the series of triplets; among the remaining lines they pointed out pairs with constant differences of wave-frequencies. Notably H and K, with a difference of wave-frequency of 222.9, and the more refrangible pair at 3737.08 and 3706.18, with a difference 223.1.

Messrs. Humphreys and Mohler in their experiments on the effect of pressure on the wave-lengths of metallic lines, found that in the case of calcium, the H and K lines were shifted only one-half as much as the blue line at 4226.9. We know far too little to justify us in forming any theoretical conclusions from this peculiarity of behavior. Indeed there are no certain reasons why the lines of any substance should be equally shifted.

It is well known that calcium, in common with nearly all substances, gives a more complex spectrum under the conditions of the arc and spark than under those of a flame. Now in the Fraunhofer lines we have, as first shown by Kirchhoff and Bunsen, absorption spectra of the elements which correspond, speaking broadly, with those of the bright-lined spectra of the same substances as they are produced by the spark. In order, therefore, to study the modifications which the calcium undergoes in the higher regions of the chromosphere, in the prominences, and possibly in lower parts of the corona, as well as in the atmospheres of stars of different orders, it was clearly desirable that we should start with an ordinary spark spectrum. It was suggested to us strongly by the known rarer state of the gases in the regions above the photosphere, as well as by my long experience with the behavior of calcium in comparison spectra, that the modifications of the calcium spectrum which we were seeking would be likely to show themselves under conditions of greatly reduced density of the calcium vapor.

EXPERIMENTS.

For reasons which will be obvious later on, we elected to use throughout the experiments a spark of very small intensity.

1. The break of a 6-inch Apps coil was fixed at the position of smallest acting force of the spring. So much battery power

only was employed as would be just sufficient to move the break. Under these conditions, when a jar was not in connection, the feeble spark would not pass when the distance between the points exceeded 1¼ inches.

2. In all the experiments a jar was intercalated.

3. The same length of exposure, a very short one of a second and a half, sufficient to bring out only the strongest lines of the spectrum, was used in each experiment.

4. Two sets of similar experiments were made; in one case with electrodes of platinum and in the other with electrodes of iron. In the latter case the chief lines of iron were present with those of calcium.

METHOD ADOPTED FOR REDUCING THE DENSITY OF THE CALCIUM VAPOR.

(*a*) The spark was taken between electrodes of metallic calcium. It was assumed, as was confirmed by the appearance of the spark, that with metallic calcium for electrodes, the largest amount of calcium vapor would be present.

(*b*) The tips of the electrodes, iron or platinum, were slightly moistened with a strong solution of calcic chloride.

(*c*) The tips were slightly washed with pure water.

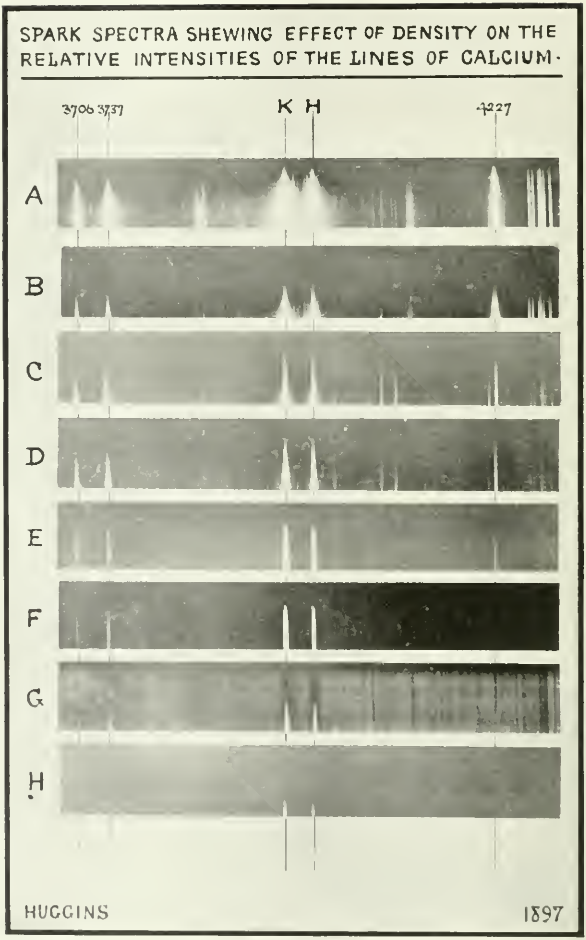
(*d*) The tips were again washed with pure water.

(*e*) The tips were then slightly moistened with a very weak solution made by adding a drop of the strong solution to two ounces of water.

Our expectations were completely confirmed. Under the conditions (*a*) of greatest density of the calcium vapor, when metallic calcium was employed, the blue line was as strong and possessed the same diffuse character as H and K.

As the density of calcium was reduced, the lines were not found to be equally enfeebled, but, on the contrary, the blue line and the greater number of the lines were increasingly reduced in intensity relatively to H and K, until at last with the twice washed electrodes (*d*) the spectrum was simplified to the con-

PLATE XIII.



SPARK SPECTRA SHEWING EFFECT OF DENSITY ON THE RELATIVE INTENSITIES OF THE LINES OF CALCIUM.
3706
3737
K
H
4227
A
B
C
D
E
F
G
H
HUGGINS
1897

dition usually existing in the prominences, in which H and K only are present.

We now proceed to a more precise statement of the changes of relative intensity as they are presented in the photographs which accompany this paper.

DESCRIPTION OF THE PHOTOGRAPHS ON PLATE XIII.

A. Photograph of the spark when both electrodes consist of metallic calcium. Here we have present doubtless the largest amount and greatest density of calcium vapor. The winged character of H and K, of the blue line, and of the pair more refrangible than H and K, is well seen, showing that this appearance comes out when the gas is dense. If the greater extension of the wings of H is allowed for, and the line H carefully distinguished from the fine lines close to it, it will be seen to possess very nearly the same strength, both as regards width and length, as the blue line at 4226.9. The strength of this blue line under this condition of density is about the same as that of the line at 3737, and rather greater than the line beyond at 3706.

B. Spark taken with one electrode only of metallic calcium, the other electrode being of platinum. In this case the effect of a smaller density of the calcium vapor is clearly shown in the greatly reduced wingedness of the lines. It will be remarked that the diminished density has had the greatest influence on the pair at 3737 and 3706; these lines are now much less strong than the blue line, which still holds its own, and remains about as strong as H and K. The lines of the more refrangible pair are no longer diffuse at the edges.

C. Spark taken between platinum electrodes moistened with a strong solution of calcium chloride. Here the effect of a smaller quantity of vapor begins to tell strongly upon the intensity of the blue line relatively to H and K. It may now be estimated at less than one-fourth of the intensity of H. At the same time H and K have almost completely lost their diffuse character, and have become thinner and more defined.

D. The electrodes as left in the former experiment were

slightly washed with pure water, leaving a trace only of calcium chloride. There is, as might be expected, an advance in the enfeeblement of the blue line and of the more refrangible pair, relatively to H and K.

E. The electrodes were again slightly washed with pure water, so that a still smaller trace of calcium chloride must have remained upon them. The enfeeblement of the blue line and of the pair has now become very great, while H and K, though thinner, remain strong.

F. The electrodes were once more washed with pure water, reducing still further the trace of calcium chloride which remained upon the platinum wires. The blue line has now practically disappeared, and the refrangible pair become very thin. The H and K lines have become thin and defined, as they usually present themselves in the prominences.

G. The electrodes remaining as they were left after the last experiment (F), the spark was taken upon a background consisting of a faint solar spectrum. The blue line has now completely disappeared, leaving H and K strong.

H. Once more the electrodes were washed, with the expectation of having removed completely the last remaining trace of calcium. To our surprise, when the photograph was developed, the lines H and K came out alone. The more refrangible pair had now faded out as well as the blue line. H and K were now thin, and extended but a short distance in the spectrum.

It must be remembered that the only condition which was varied during this set of experiments was the amount or density of the calcium vapor. The changes of relative intensity, and the modifications of the calcium spectrum produced thereby as shown in the succession of photographs on the plate, correspond closely to the behavior of calcium at different levels near the Sun's limb, and in the atmospheres of stars of different orders. There can remain no doubt that the true interpretation of the changes in appearance of the calcium lines in the celestial bodies is to be found in the different states of density of the celestial gases from which the lines are emitted or by which they are absorbed.

A similar set of experiments was made with iron electrodes. Precisely similar results as to the relative enfeeblement of the lines, as with calcium chloride on platinum electrodes, were obtained. Of course the iron lines were also present. As might be anticipated, in consequence of the simultaneous presence of the iron vapor, the lines of calcium were thinner than when platinum was used.

Outside the range of wave-lengths which could be conveniently given on the plate, far on in the ultra-violet, there is a pair of strong lines which behave very much as H and K. It remains visible in photograph II, when the pair at 3737 and 3706 have disappeared. This pair is situated at 3158.98 and 3179.45.

It is desirable to point out again that all the photographs on the plate and the far ultra-violet lines, were obtained with a spark of quite unusually small intensity, which was purposely made as little hot as possible, in order to emphasize the important fact that the determining condition of the spectral changes under discussion is not one of increase of temperature.

In the modifications of the calcium spectrum arising from variations in the relative intensities of the lines which have been discussed in this paper, and which correspond to those observed in the celestial bodies, there does not appear to us any reason for assuming, much less any direct evidence in favor of, a true dissociation of calcium, that is, of its resolution into chemically different kinds of matter.

It would be remarkable if, by decomposition through increase of temperature, a large number of lines of a spectrum should become relatively enfeebled, and that as the result of decomposition a spectrum should become simpler, and not as analogy would suggest, more complex.

It is of importance to keep in mind that the recent chemical use of the word *dissociation* is not equivalent to true decomposition, *i. e.*, to a resolution of the original substance into two or more chemically different kinds of matter. It may, and does often mean not more than a different arrangement of the parts of the molecule, while those parts are all chemically matter of the

same kind as the original molecule. As in the case of the resolution of a compound molecule of peroxide of nitrogen into two identical half molecules; or, in the separation of a molecule of elementary iodine into two half molecules or atoms of identical chemical characters. Such dissociations are well known, and are not of infrequent occurrence, and may, indeed, take place in connection with some of the spectral changes of a substance observed under different conditions. On the other hand, a true decomposition of a chemical element, that is, a breaking up of the molecule into simpler and quite other kinds of matter, though a notion familiar to chemists since Prout's time, and regarded as theoretically possible, is, as yet, unknown as a matter of fact.

CONCLUSIONS.

These experiments seem to us to furnish an adequate and consistent explanation of the behavior of the calcium lines at and near the Sun's limb. Near the photosphere, where the absorption mainly takes place by which the dark lines of the solar spectrum are formed, there would be, we should expect, a much greater density of calcium vapor than at a higher level, and we find the Fraunhofer line at 4226.9 strong but much less broad than H and K. The recent photograph of the reversing layer shows that the broad shading of H and K is not produced there, but probably, as Mr. Jewell concludes from his measures, lower down where the gas is still denser, which is in agreement with photograph *A* on the plate.

Higher up in the chromosphere, in the prominences, and possibly in the lower coronal regions, the decrease of the density of the gases composing them must be rapid, and the temperature gradient as determined by expansion must be rapid. We have clearly to do, in these regions, with calcium vapor in a rarer state, and except so far as the molecules may have carried up within themselves to some extent the higher heat of a lower level, or through imperfect transparency, the gases may have received heat from the Sun's radiation, it must be at a much lower temperature than near the photosphere Now, the changes of the calcium spectrum which take place in these regions, are

those which correspond in our experiments to a very small amount of calcium vapor, and a spark of small intensity.

On account of the violent commotion which must exist through the strong convection currents at the Sun's limb, we should not be surprised to find some calcium vapor, notwithstanding its greater density, carried high up together with the lighter substances such as hydrogen and helium. Our experiments show how strongly the H and K lines may come out when a trace only of calcium vapor is present, and so, it seems to us, offer a possible explanation of the great height at which these lines may be sometimes recognized. At no very great distance from the surface of the Sun the gases must become too tenuous to give a visible spectrum, and it may well be that the brilliant radiations of even very rare calcium gas at H and K may show in our instruments for some distance after the hydrogen and the other light matter associated with it, have become too subtle to furnish a spectrum that we can detect.

The relative behavior of the lines of the calcium spectrum as they present themselves in the different orders of stellar spectra, when interpreted by the terrestrial experiments described in this paper, will throw important light on many of the important questions which are still pending in celestial physics. In forming conclusions as to the state of the stellar atmospheres from the different densities which may be indicated by the modifications of the calcium spectrum, it must be borne in mind that, as I have said elsewhere:

> "The conditions of the radiating photosphere and those of the gases above it, on which the character of the spectrum of the star depends, will be determined not alone by temperature, but also by the force of gravity in these regions; this force will be fixed by the star's mass and its stage of condensation, and will become greater as the star continues to condense." [1]

It may be, though on this point we have no sufficient data, that though the stars are built up of matter essentially similar to that of the Sun, the proportion of the different elements is not the same in stars which have condensed in parts of the heavens widely distant from each other, or at epochs greatly separated in time.

[1] Address, *Report Brit. Assoc. A. Science*, 1891, p. 15.

It does not seem desirable to discuss any of these questions at the present time, as we hope before long to offer some explanation of the, to some extent analogous, relative behavior of the lines of some other substances as observed in the Sun and stars.

Addendum.—The following letter from our friend Professor Liveing, which he has given us permission to publish, contains an account of early experiments on the spectrum of calcium, which not only support, by a different method of working, the conclusions of our paper, but also seem to show the possible occurrence of the line H, without the line K. In our experiments, as will be seen in the spectra on the plate, both lines are alway present, while the line K is stronger and longer than the line H; which agrees with the photographs of the prominences taken by Hale, and by Deslandres.

"I have been looking up some observations of Dewar's and mine on the H and K lines of calcium made in 1879. We found that when we used, for the arc, carbon poles which had been heated for two days in chlorine to remove metals, the calcium lines were not at first visible in the arc, but after a time H was seen alone and not strong, after a further time K was seen, and then other calcium lines came out. No doubt the calcium had been pretty well removed from the carbon rods to some depth, but not entirely from the interior, so that as the carbon burnt away in the arc the calcium in the interior became manifest.

"Again we found that when we used a perforated pole and passed a stream of hydrogen into the arc through it, H and K could be both entirely obliterated; but by then reducing the current of gas they gradually reappeared, and H always came out first and afterwards K, and H remained stronger than K until they had both become strong, and had resumed their ordinary appearance. This was seen many times.

"Both observations seem to me to confirm your conclusions. In the latter case the stream of hydrogen diluted the calcium vapor, and the degree of dilution was controlled by the rate at which the gas was introduced. The mass of gas passing was too small to reduce the temperature by any considerable amount, or even, I should think, by any sensible amount.

"We found also that metallic lithium introduced into the arc produced effects similar to those produced by hydrogen, that is, it reduced very much the strength of the H and K lines. If more than a very minute piece of lithium were introduced the arc was invariably broken, so that we did not notice the complete obliteration of H and K with the lithium. The reduction of the strength of H and K in this case I attribute to the dilution of the calcium vapor by that of lithium."

THE NEW PHOTOGRAPHIC CORRECTING LENS OF THE EMERSON McMILLIN OBSERVATORY.

By H. C. Lord.

In a paper published in the Astrophysical Journal for February 1895, Professor James E. Keeler describes a lens, which, placed a short distance above the slit of a compound star spectroscope, so alters the color curve of the large objective, as to render it flat in the photographic portion of the spectrum. He there calls attention to the fact that if this lens be compound the correction can be secured without materially altering the focus for any selected ray. The use of a single lens of this nature is described by Professor H. F. Newall in a paper on the Bruce spectroscope published in the *Monthly Notices of the Royal Astronomical Society* for January 1896; but, so far as I am aware, the compound lens has never before been tried in actual practice. I trust, therefore, that the description of such a lens, in use at the Emerson McMillin Observatory, may be of interest to the readers of the Astrophysical Journal.

The spectroscope is fully described by the author in Vol. 4, No. 1 of this Journal. As soon as possible after the completion of the Observatory, the color curve of the 12½-inch objective was determined, observations being made on three different nights. This curve, together with the plotted observations, is given in a plate which accompanies this article. Numerous attempts were made to photograph stellar spectra in the neighborhood of $H\gamma$ without success, as it was found absolutely impossible with the slit set at the focus for this line, to tell whether or no the star's image was within the jaws of the slit. Professor Keeler, in the article above quoted, has called attention to the fact that this difficulty must always be experienced when attempting to photograph with a visually corrected objective. In order to test the accuracy of the following, the camera of the spectroscope was replaced by the observing telescope, and

the star brought on the slit by means of the device for following. In almost every case the star's spectrum was not seen in the observing telescope. In this way it was found that the limit at which accurate following was possible was but slightly to the violet side of the $H\beta$ line. The spectra were, moreover, excessively short and even a slight change of focus caused the point of maximum density of the spectrogram to shift by a considerable amount. It was decided, therefore, to provide the telescope with a compound correcting lens. Mr. Emerson McMillin, the founder of the Observatory, generously furnished the necessary funds. The color curve of the large objective was sent to Mr. Brashear and from it the curves of the lenses of the compound correcting lens were computed. The corrector is 76^{mm} in diameter and is fitted to a long brass tube which screws into a sleeve fastened to the inside of the breech piece of the telescope tube, holding the lens 1011^{mm} above the uncorrected focus for $H\beta$. The method of support is most excellent. It is very rigid and can be removed inside of two minutes. As soon as it was received the color curve was determined and is given, together with the plotted observations, in Plate XIV. I give below a table which gives both for the corrected and uncorrected objective the distance of the foci for the several rays, from a point one meter above the uncorrected focus for $H\beta$. In Plate XIV are given two sets of curves. The first are the two color curves with ordinates focal lengths from a fixed point, and abscissæ wave-lengths. The advantages of the new lens when used with a prism spectroscope are best brought out by the second set of curves. Here the ordinates are as before, but the abscissæ are the deviations produced by two dense 60° prisms, such as are in use with this spectroscope. The scale is so taken that the distance from B to h is nearly the same in both sets of curves. Since photographic action ends slightly below $H\beta$, this combination may be called practically achromatic for the photographic portion of the spectrum.

The effect of the corrector on the ease of following is very marked. With the slit set at the corrected focus for $H\gamma$, and my

PLATE XIV.


COLOR CURVES
12½ OBJECTIVE & PHOTOGRAPHIC CORRECTOR
EMERSON McMILLIN OBSERVATORY
ABSCISSAE WAVE LENGTH
ORDINATES FOCAL LENGTH FROM FIXED POINT
COLOR CURVES.
12½ OBJECTIVE & PHOTOGRAPHIC CORRECTOR
EMERSON McMILLIN OBSERVATORY
ABSCISSAE DEVIATION TWO DENSE 60° PRISMS
ORDINATES FOCAL LENGTH IN mm FROM FIXED POINT

assistant stationed at the observing telescope of the spectroscope, I watched the star's image in the device for following, which is similar to that in use at Potsdam, and by means of the declination slow motion, threw the star off and on the slit, calling out to him when the spectrum should be seen. Without telling me he noted the times it appeared. Out of twenty trials I failed but once. By removing the eyepiece of the following telescope (a plan suggested by Professor Keeler) following is very easy; the slighest pressure on the supporting rods of the spectroscope is at once detected. With Dr. Huggins's reflecting slit following is still more certain. The star's image is very peculiar; a green central point is surrounded by a bright halo of red rays and no difficulty has been experienced in bisecting the central green point with the slit.

In order to measure the field of the new lens the slit was removed from the collimator and a rough, homemade photochronograph[1] put in its place. This was connected with the standard clock of the Observatory and an exposure of about one-tenth of a second given every second as the star was allowed to trail across the plate. When developed the plate showed a series of small dots or circles, which, when examined under the microscope, appeared sharp and distinct over about $5^{mm}.3$, after which they rapidly degenerated into more and more elongated ellipses, whose major axes pointed to the center of the field. This distance gives a field of about four minutes of arc, much larger than is needed in spectroscopic work.

As a further check upon the color curve a photograph of α Lyræ was taken with the slit set parallel to an hour circle, in order to secure a spectrogram which should be as narrow as possible. An exposure of 15^{m} showed $H\beta$, $H\gamma$, and $H\delta$, and both H and K, but the last two faintly. From $H\beta$ to $H\delta$ the spectrum is of almost uniform density but of course greatly over-exposed. The lower limit of the photograph reaches nearly to the little *b*'s. Its width is at $H\beta$ $0.^{mm}132$, at $H\gamma$ $0.^{mm}068$, and at $H\delta$

[1] "The Photochronograph and its Applications," *Publications Georgetown College Observatory*.

$0.^{mm}064$ approximately. Possibly the best testimonial to the advantages of this lens is shown in Plate XV. The two spectra are I, the Sun, and II, that of Arcturus. The latter extends from below $H\beta$ to above $H\delta$. It should be stated that the relative densities of the different portions of the photograph of Arcturus have been controlled by what might be called a paint brush method of development, my object being to show what extent of spectrum could be secured on one plate. I should also state that the enlargement was made with a home-made piece of apparatus and of course the sharpness of the lines in the original negative suffered more or less.

TABLE I.

Wave-length	Distances of Foci from a point 1^m above uncorrected Focus for $H\beta$	
	Uncorrected Lens	Lens with Corrector
B	$998^{mm}.8$	$1034^{mm}.2$
C	997 .8	1031 .1
6300	997 .1	1028 .6
D	996 .5	1024 .6
5500	996 .6	1021 .0
E	997 .1	1018 .9
b's	997 .6	1018 .0
$H\beta$	1000 .0	1014 .3
4600	1003 .9	1013 .4
$H\gamma$	1010 .7	1012 .8
h	1018 .0	1012 .9

EMERSON MCMILLIN OBSERVATORY,
June 16th, 1897.

PLATE XV.

Photographed by Prof. H. C. Lord.

I. SPECTRUM OF THE SUN.

II. SPECTRUM OF ARCTURUS.

ON THE LEVEL OF SUN-SPOTS AND THE CAUSE OF THEIR DARKNESS.

By A. Riccò.

In the October 1896 number of the Astrophysical Journal Professor E. B. Frost has again called in question the theory of Wilson on the level of Sun-spots. He presents important physical considerations, and shows that spot statistics obtained from drawings or photographs have not given definitive results in demonstration of the fact that the spots are cavities.

These considerations have led me to bring together statistics derived from a series of drawings of Sun-spots made by the method of projection in the years 1880 to 1890 at Palermo, with a refractor of $0^{m}.25$ aperture, and at Catania in 1892 with a refractor of $0^{m}.33$ aperture. The diameter of the projected solar disk was in all cases $0^{m}.57$, large enough to show satisfactorily the principal details of the spots.

In bringing together the statistics I have omitted the drawings of the first year, 1880, since it is probable that at that time I had not acquired sufficient skill to represent the Sun-spots with the necessary exactness. The break in 1891 was caused by the fact that the Catania refractor had not then been mounted. I might have filled this gap by using the observations continued by Professor Mascari at Palermo, but I have preferred not to do this in order to render the series as nearly as possible homogeneous.

In these eleven years the number of days of observation was 3451 and the number of drawings of spots 17,436 (excluding the pores), of which 3324 represent different spots. Rigorously excluding all spots not perfectly regular in form, *i.e.*, round and symmetrical when near the center of the Sun's disk, there remain only 185 drawings suitable for the study of the question. The following table gives the data regarding the width of the penumbra on the side toward the Sun's limb and on the opposite side:

Year	Penumbra of regular spots		
	Wider toward the limb	Narrower toward the limb	Symmetrical
1881	28	0	9
1882	16	7	2
1883	19	2	2
1884	22	5	4
1885	15	1	0
1886	10	0	6
1887	7	0	0
1888	0	1	0
1889	1	0	3
1890	2	1	1
1891	..	.	.
1892	11	1	3
Total	131	18	36

It is seen that in each of the eleven years (except 1888, when there was but one regular spot), the number of spots near the limb whose projected form gave a result conforming to the theory of Wilson is much greater than the number of contrary or uncertain cases. From the entire eleven years we have the proportion of cases favorable, unfavorable, and neutral to the theory of Wilson:

favorable : *unfavorable* : *neutral* .: 7.3 : 1 : 2

Greater weight must be given to the still more significant cases of spots near the Sun's limb, the penumbra of which, conforming to the appearance of a cavity seen in perspective, is invisible on the side opposite the limb. I have found twenty-three cases of this sort in the eleven years, and only one contradictory case.

It must be added that if it is admitted that the umbra and the penumbra of spots are like dark clouds elevated above the photosphere, it is necessary to suppose that they are enveloped by the tongues and flames rising from the photosphere, which are frequently observed across the spots, where they diffuse into the nucleus; and the best drawings of large spots made by the ablest observers, distinguished astronomers, and skilful draughts-

men (for example, the "typical spot" of Langley) would be wholly incomprehensible.

It must, therefore, be admitted that the spots are cavities, *i. e.*, breaks or openings in the photospheric layer; but it is very difficult to say what is the condition of the materials which they contain and which are the cause of the darkness of the umbra and penumbra. In fact: (1) the thermal, visible, and actinic radiations of the spots are in general less intense than those of the photosphere; but (2) these radiations have almost the same intensity when the spots are near the center of the Sun as when they are near the limb; (3) the temperature of the Sun increases rapidly in passing toward the interior layers; and (4) the outlines of the penumbra and the umbra are not diffuse, but are clearly defined. These reasons (2, 3, 4) do not permit the conclusion that in the spots there is a substance which absorbs on account of its lower temperature. On the contrary, (3) would rather lead us to suppose that in the spots there is a substance but slightly luminous on account of its excessively high temperature; but in this case, as Mr. Evershed[1] has very properly pointed out, it must also be very transparent; hence the radiations of the internal layers would be integrated and the obscurity should disappear, or rather one should be able to see the radiations of the photosphere on the opposite side of the Sun.

To avoid this difficulty Mr. Evershed has suggested the very ingenious hypothesis that on account of the high temperature of the materials contained in the spots, the radiations of short wave-length must be increased while those of greater wave-length are diminished, so that the spots should be particularly rich in ultra-violet light, *i. e.*, dark to our eyes. But they must have a photographic action, while as a matter of fact the penumbra and umbra of spots are dark in solar photographs. To avoid this difficulty we must suppose with Mr. Evershed that the absorption exercised on the radiations of short period by the terrestrial atmosphere (as is demonstrated by the red color of the Sun at the horizon), and also perhaps, as it seems to me,

[1] This JOURNAL, April 1897, p. 296.

by the solar atmosphere (demonstrated by the dark reddish color of the Sun's limb), is strong enough to suppress the actinic action of the nuclei of Sun-spots.

In considering the relations which are known to exist between radiations of short period and electrical phenomena, the suggestion of Mr. Evershed that the radiations peculiar to Sun-spots, although invisible, may be the cause of the perturbations of terrestrial magnetism which coincide with the presence of large spots on the Sun's disk, seems to me of the greatest importance. Such a coincidence cannot be denied, as I have myself pointed out.[1]

In conclusion, considering the importance of the problem of the constitution of Sun-spots and the difficulties which stand in the way of its solution, we may echo the wish expressed by Mr. Evershed that the radiations of Sun-spots may be studied in a more complete manner. It is to be hoped that Professor Hale, who has long intended to make a detailed and complete study of spots, may be able to carry out his project now that he has at his disposal the admirable instrumental equipment of the Yerkes Observatory.

CATANIA OBSERVATORY,
May 5, 1897.

[1] *C. R.*, October 17, 1892; *Mem. Spettr. Ital.*, **21**, 153.

INVESTIGATION OF THE VIOLET PART OF SOME METALLIC SPECTRA WHICH CONTAIN MANY LINES.[1]

By O. Lohse.

While investigating the spectra of a considerable number of metals within the region λ 4000–λ 4600 by means of a spectrograph, I found several that were remarkable on account of the great number of lines which they contained. They were mainly spectra which are only imperfectly known, at least in the region which I have studied, and I believe therefore that the following communication concerning the wave-lengths of the lines will not be without interest. It is my intention to repeat the investigation of the spectra of these metals with the aid of a concave grating, and to extend it to other parts of the spectrum; hence I regard the observations here given as only preliminary.

The spectrograph which has been used in this investigation has a direct-vision prism filled with ethyl cinnamate and closed at the ends by plates which are perpendicular to the axis. On one of these plates a total-reflecting prism is so placed that the rays which come from the collimator and fall on the upper half of the fluid prism are reflected back through the lower half. The dispersion is therefore very considerable, and the linear extent of the spectrum, between the wave-lengths above mentioned, is 180^{mm}. The collimator objective has a focal length of about $\frac{3}{4}^{m}$ and is achromatized for the chemically active rays. A single plano-convex lens of 1^{m} focal length was used as a camera objective, as I found that an achromatic lens gave no better result than the former and absorbed more light. Both objectives have an aperture of 40^{mm}.

The apparatus, which is mounted on a heavy cast-iron pillar, was made in the well-known shops of O. Toepfer, in Potsdam;

[1] "Untersuchung des violetten Theils einiger linienreicher Metallspectra." *Sitz. d. K. Akad. d. W. Berlin*, **12**, 179–197, 1897.

it is satisfactory in all respects, and observations are made with remarkable ease and certainty. The slit, which has platinum-iridium jaws, is vertical. It has an attachment which can be moved up and down, so that as many as seven narrow spectra can be photographed one over another on the same plate, though the whole length of the slit can also be used. The camera to which the plate-holder is secured is provided with a bellows; it moves along a planed track of cast-iron, furnished with a graduated scale. Since my observations were confined to spark-spectra, for reasons which I will refer to further on, I adopted an arrangement by which a condenser, made by me of a combination of lenses and a silvered-glass mirror, and intended to increase the light from the spark, could be moved up and down in front of the slit, together with the horizontal electrodes.

The electric current necessary to operate a large induction coil 39^{cm} long was generated by a dynamo, which was driven by a gas-engine. Since the current strength required was only a small fraction of that furnished by the dynamo, and it was necessary to protect the coil from the effects of too great a current, a sufficiently high resistance was always interposed and a shunt circuit used for the coil, the strength of which could be reduced still further by increasing the same resistance. With the aid of this arrangement a very uniform stream of sparks was obtained.

In photographing with this instrument the greatest difficulties naturally arose from the influence of heat on the refractive power of the ethyl cinnamate, an influence which is so great that perceptible effects are caused by changes of temperature that do not admit of measurement with even the more delicate thermometric instruments. This caused with rough contrasts inferior definition of the lines; in general only continuous wandering of the spectrum was produced, which was prohibitive of long exposures. A further result of the wandering of the spectrum was that the distance of the focal plane from the objective was altered, particularly in oblique positions of the photographic plate. It was not until I had taken account of this effect and

focused anew for each series of experiments that I succeeded in obtaining uniform results.

On account of the uninterrupted motion of the image I was further compelled, in order to obtain reliable points of reference, to photograph at the same time the spectrum of iron, the lines of which are easily identified in the solar spectrum. This was very easily done by always taking iron for one of the two electrodes, in which practice it only very rarely happened that the superposition of lines necessitated the taking of additional photographs with electrodes of the same kind.

In all photographs of metallic spectra the exposures were seventy seconds, with a slit-width of $0^{mm}.03$.

The photographs were measured with the aid of a simple apparatus, which consisted essentially of a microscope with micrometer eyepiece, mounted on a table. With this arrangement it was possible to measure only a short range of the spectrum, corresponding to the circumscribed field of view of the microscope.

The micrometer screw was cut by Herr Toepfer, and its periodic errors were so small that they were without perceptible influence on the accuracy which was aimed at in the measurement of wave-lengths; hence the direct readings of the micrometer could be used.

All measures were referred to the solar spectrum, on a particularly good photograph of which I had indicated by figures the normal lines accurately determined by Rowland. Forty-seven of these normal lines were used in the region between λ 4000 and λ 4600.

This photograph was fastened once for all to the glass stage of the measuring apparatus, and the metallic spectrum was laid upon it, so that the two films were in contact, and the lines as nearly as possible in coincidence.

The latter adjustment was effected with the aid of the iron lines, which are easily recognized in the solar spectrum, through their regular arrangement, when the iron spectrum is held opposite to it. An exact coincidence throughout the whole spectrum

could not, however, be attained, on account of the changes of refraction and dispersion caused by variations of temperature. There were no two plates which were quite the same in this respect. In making the measurements care was taken that at least one of the normal lines above mentioned was in the field of the microscope. Its position was generally determined by three, sometimes by more, settings; then several iron lines were measured, in both the solar and the metallic spectrum, in order to determine the fortuitous relative position of the two spectra, after which the measurement of all the lines in the field of view was begun, with three settings on each line. The displacement of the metallic spectrum relatively to the solar spectrum could in most cases be regarded as constant for the region included in the field of view; in only a few photographs, which were taken at a temperature widely different from that at the time of taking the solar spectrum, were the differences of dispersion found to be so considerable that the displacement had to be regarded as variable even within the field of view.

The relation between the micrometer revolutions and wave-lengths was found by measuring in succession the greater part of the normal lines in the solar spectrum, in such manner that the measurements were connected, each new series beginning with the last line of the preceding series. As the field of the microscope was comparatively small, thirty series were necessary. The entire length of the spectrum was then subdivided into smaller parts, for each of which the necessary reduction factors were determined by the method of least squares. It was found that at least seven subdivisions were necessary in order to find the wave-lengths with the requisite precision when terms of the second order were taken into account. After the completion of the computations a number of tables were made, by which the change from revolutions to wave-lengths was much facilitated, so that the labor of determining the wave-lengths of the metallic lines was not so great as one might be led to suppose from the foregoing account of the process.

The uncertainty of the wave-lengths deduced from my

measurements does not ordinarily much exceed 0.1 Ångström's unit; the existence of a greater error is probable only when the corresponding line is extremely faint, so that it could not be seen without difficulty, or when its breadth was unusually great.

In cases where comparisons were possible, I have found that my results agree satisfactorily with other recent observations, and in particular with the tables of Rowland, published in the Astrophysical Journal, where special prominence is given to those lines of the solar spectrum which coincide with metallic lines. On the average, some 20 per cent. of the lines of cerium, lanthanum, yttrium, zirconium and vanadium which I have observed are found in these tables, so that a valuable check on the work was thus obtained.

The reason for limiting the investigation to the region λ 4000—λ 4600 was, originally, that it seemed chiefly desirable to learn the positions of metallic lines in the violet part of the spectrum where the greatest photographic activity is manifested, and thus to obtain data which would be useful for comparison with spectographic observation of the heavenly bodies. In the course of the work I remarked that the investigation of a large number of substances at the same time, within the same limited region of the spectrum, has certain advantages, in that it enables one to immediately recognize accidental and unexpected impurities. As a proof of the identity of lines I constructed a table having wave-lengths as arguments, with intervals of 0.1 tenth-meter. The observed metallic lines were gradually inserted in this table, by which process it was at once recognized when any particular place was already occupied by a line of another metal. In places where a large collection of figures occurred, which did not differ from one another by more than the probable error of observation, it was certain that the existence of some element as an impurity in a number of metals was indicated. The identification of this element was effected with certainty by comparing the tabulated intensities of the lines.

In recent times the investigation of metallic spectra by means of the induction spark has fallen somewhat into the back-

ground, and the principal spectroscopists have used the electric arc for vaporizing metals. The cause of this fact appears to be that, in consequence of the variations of temperature with one and the same metal in the arc, a greater number of lines make their appearance than in the spark spectrum. But it is precisely this difference which offers much that is of interest, and renders a continuation of the investigation of spark spectra desirable. I have, therefore, adopted the latter method. The induction spark has the further advantage over the electric arc that it does not give rise to an accompanying continuous spectrum, and that hence the lines appear on a dark ground; and, finally, the consumption of the material of which the electrodes are composed is very slight — a consideration of some importance where so many rare metals are concerned.

At first I did not consider that it would be possible to use other than metallic electrodes, but as the investigation would thereby have been limited to a small number of metals, I finally used compounds also. The chlorides or nitrates soluble in water were always chosen. Sticks of charcoal (following Bunsen) were saturated with the solution after they had been heated to dull redness. These sticks served as electrodes and proved to be very good. At the great heat of the electric spark the compounds were reduced by the carbon, furnishing the requisite quantity of metallic vapor in a state of comparative purity and in an economical manner. The existence of other substances was easily recognized by the constant recurrence of certain lines.

With regard to the following tables it is to be mentioned that the intensities were estimated on a scale of 10, so far as this was possible without the aid of other methods. The intensity 1 indicates a very weak line, 10 a very strong line. Smaller steps than those given by this scale of intensity could be observed, particularly toward its lower limit, but, to avoid carrying the system too far, they were not taken into account.

When *u* is printed in place of the intensity, or as a subscript to figures expressing intensity, it is intended to signify that the corresponding line is not sharply defined.

In the case of wave-lengths which are given in demonstration of accidental coincidence or of indentity, the intensities according to my estimates are printed as subscripts to the customary abbreviations of the names of the metals; subscripts to other wave-lengths also indicate intensities.

CERIUM; LANTHANUM; DIDYMIUM.

Since it was not to be expected that metallic cerium could be obtained in pieces sufficiently large to serve as electrodes, I used the chloride according to the method already described. This and all other preparations were furnished by Dr. Schuchardt, of Görlitz, Silesia. I suspected contamination by lanthanum and didymium, and therefore photographed the spectra of these two metals on the same plate with that of cerium. The generally strong lines of lanthanum were also noticed in the spectra of cerium and didymium. Although all the lanthanum and cerium lines were eliminated from the cerium spectrum during the process of measurement, there still remained some 400 cerium lines in the small range of spectrum which was measured. Of all metals, therefore, cerium may be regarded as that possessing the greatest number of spectral lines in the violet. The spark spectrum of iron within the same region on my plates showed about 130 lines.

SPECTRUM OF CERIUM.

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity
4016.01	2		4027.82	3
4017.06	1		4028.53	4
4017.69	2		4030.47	3
4019.18	3		4031.46	4
4020.22	2		4032.74	1
4020.65	1		4037.83	3
4020.97	1		4038.41	3
4021.43	1		4040.03	1
4021.90	1		4040.89	5
4022.40	3		4041.46	1
4024.62	4	$4024.66Zr_6$	4042.29	1
4025.24	2	$4025.14Zr_4$	4042.71	4

SPECTRUM OF CERIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4042.90	2		4083.78	2	
4045.40	2	$4045.92 Zr_6$	4085.39	4	
4045.97	5		4086.59	1	
4046.49	3		4087.48	3	
4047.46	1		4087.66	1	
4049.19	1		4088.76	1	
4050.99	1		4089.02	3	
4051.54	2		4089.91	2	
4052.16	2		4090.63	2	$4090.68 Zr_6$
4053.65	3	$4055.16 Zr_5$	4091.11	2	
4055.13	3		4092.25	1	
4055.25	1		4092.86	2	
4056.38	1		4094.11	2	
4057.00	2		4099.13	2	
4058.37	1		4099.94	1	
4058.91	1		4101.93	4	
4060.05	1		4102.62	2	$4102.56 Y_3$
4060.60	2		4104.59	1	
4060.83	1		4105.16	3	
4061.23	2	$4061.28 Di_3$	4106.28	1	
4062.36	3		4107.02	3	
4063.08	2		4107.55	4	
4064.06	1		4107.95	1	
4065.08	1		4108.41	1	
4065.16	1		4108.84	1	
4066.69	1		4110.53	3	
4067.43	3		4111.01	1	
4067.91	1		4111.51	3	
4068.15	1		4112.07	1	
4068.60	2		4113.86	2	
4068.96	4		4114.22	1	
4070.24	3		4115.48	4	
4071.00	1		4117.10	3	
4071.22	1	$4071.26 Zr_3$	4117.40	2	
4071.89	6		4117.70	3	
4073.07	2		4118.24	6	
4073.60	6		4119.13	3	
4073.87	3		4119.94	7	
4074.28	1		4120.94	4	
4074.80	1		4123.57	4	$4123.46 La_{10}$
4075.26	1	$4075.14 Zr_4$	4123.95	7	
4075.93	9		4124.88	4	
4076.42	3		4125.55	1	
4077.61	5	$4077.58 La_9$	4125.88	1	
4078.86	2		4126.74	1	
4079.46	1		4127.44	6	
4079.89	2_n		4127.81	3	
4080.64	2		4128.13	2	
4081.38	5		4128.44	3	$4128.49 Y_4$
4083.38	6		4129.29	1	
4083.64	2		4129.84	1	

SPECTRUM OF CERIUM—*continued.*

Wave length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4130.81	4	4130.85 Ba_{10}	4187.41	4	
4131.26	4		4190.74	2	
4132.45	1		4191.17	1	
4132.81	1	4132.91 Th_4	4193.37	7	
4133.95	8		4194.05	3	
4135.55	4		4195.07	2	4195.00 Zr_5
4136.05	1		4196.00	1	
4137.04	2		4196.54	5	
4137.73	9		4197.79	2	
4138.26	3		4198.18	2	
4138.55	3		4198.87	7	
4139.65	1		4199.33	1	4199.34 Zr_5
4140.14	1		4201.53	3	
4141.00	1	4140.22 Zr_2	4203.18	5	
4142.63	5^n		4205.07	1	
4143.07	3		4205.37	1	
4143.40	1	4143.01 Y_4	4206.09	1	
4143.67	1		4208.64	1	
4144.12	3		4209.65	2	
4144.75	3		4213.30	1	
4145.26	5		4214.31	2	
4146.50	3		4222.88	6	
4148.45	1		4224.21	1	
4149.16	3		4224.85	1	
4150.15	9		4228.02	4	
4151.14	4		4228.57	1	
4152.22	8	4151.18 Zr	4230.45	1	
4153.38	2		4232.04	3	
4154.35	1^n		4232.27	1	
4155.56	1		4232.60	1	
4155.75	2		4234.44	2	
4159.22	4		4235.01	1	4234.90 Zr_4
4160.28	2		4236.51	1	
4161.30	2		4238.11	1	
4161.98	1		4240.14	5	
4162.81	1	4161.98 Sr_{10}	4242.30	1	
4163.67	4	4162.88 Th_2	4243.00	4	
4165.73	7		4244.05	1	
4166.35	1		4246.18	4	
4166.77	1	Not separated	4246.99	3	
4167.00	1		4248.26	1	
4167.91	4		4248.93	5	
4169.95	5		4251.92	1	Not separated
4172.22	2		4252.08	1	
4174.53	2		4253.60	3	
4175.34	1		4254.99	1	
4176.12	1		4255.97	3	
4176.78	3		4256.30	2	
4179.22	3		4257.37	1	
4185.46	3		4258.97		Band
4186.70	8		4259.93	1	

SPECTRUM OF CERIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave length tenth meters	Intensity	
4261.34	1		4332.98	2	
4264.08	1		4335.16	1	
4264.55	2		4335.81	1	
4266.10	1		4336.54	3	
4267.34	1		4338.08	5	
4268.03	1		4339.06	1	
4268.49	1		4339.66	3	
4269.44	2		4340.97	1	
4270.35	3		4342.52	1	4342.50 Zr
4270.86	3		4342.86	1	
4271.92	4		4344.24	1	
4273.62	2		4344.71	1	
4274.68	1	4273.68 Zr_6	4345.23	1	
4275.63	3		4346.27	2	
4278.42	1		4346.81	1	
4279.02	2		4347.99	1	
4280.29	2		4350.12	4	
4281.12	2_n		4350.78	1	
4283.67	1		4351.60	1	
4284.60	1		4352.36	1	
4285.53	4		4352.99	4	
4288.85	2		4353.71	2	
4289.66	2		4355.72	1	
4290.16	6		4357.18	1_n	
4292.93	3		4358.34	1_n	
4294.83	1		4359.39	1	
4296.90	8		4360.54	1	
4299.55	4		4360.74	1	
4300.50	4		4361.94	2	
4302.81	2		4363.75	1	
4303.77	2		4364.43	1	
4304.45	1		4364.91	4	
4304.97	1		4367.24	1	
4305.31	3		4367.75	1	
4306.95	5		4368.48	1	
4308.08	5		4369.51	1	
4309.93	4		4370.91	1	
4311.01	2		4372.61	1	
4311.95	2		4374.01	3	
4313.45	1		4376.03	3	
4314.84	1		4380.30	1	
4315.75	1		4382.09	1	Not separated
4317.59	2	4317.47 Zr_5	4382.38	5	
4318.29	1		4385.93	1	
4319.34	1		4387.04	5	
4321.04	4		4388.24	2	
4325.07	2		4390.55	2	
4327.11	1		4391.93	5	
4328.23	1		4393.42	2	
4330.74	2		4395.04	2	
4332.07	2		4396.28	1	

SPECTRUM OF CERIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4396.87	1		4477.48	1	
4397.52	1		4479.67	3	
4398.19	1		4483.66	1	
4399.00	2		4484.16	4	
4399.48	4		4485.08	2	
4400.86	1		4485.80	1	4485.76 Zr_2
4401.09	2		4487.20	4	
4403.62	1	4403.63 Zr_5	4494.49	2	
4405.65	1		4496.00	1	
4407.58	2		4496.50	2	
4409.11	2		4498.11	2	
4410.90	5		4500.57	1	
4412.17	n		4501.99	1	
4413.35	1		4508.29	1	
4414.02	1		4509.38	1	
4417.08	2		4510.32	1	
4418.99	5		4511.11	1	
4422.77	1	4422.76 Y_5	4511.82	1	
4423.84	2		4515.97	1	
4424.53	2		4519.73	1	
4427.28	2		4523.23	4	
4428.08	2		4527.30	4	
4428.65	2		4528.71	5	
4429.44	4		4532.73	1	
4433.01	1		4537.16	1	
4434.01	1		4538.21	1	
4434.58	1		4539.33	1	
4441.97	1		4539.99	4	
4443.98	2		4545.21	1	
4444.70	4		4549.90	1	
4444.95	5		4550.58	1	
4449.59	5		4551.54	2	
4450.94	4		4555.67	1	4555.63 Zr_4
4452.51	1		4560.45	4	
4458.03	1		4561.20	2	
4460.52	6		4562.57	5	
4461.50	3	4461.44 Zr_5	4566.04	2	
4463.77	3		4579.39	1	
4465.03	2		4582.65	2	
4465.78	1	4465.73 Th_3	4591.35	1	
4466.93	1		4594.06	4	
4467.85	2_n		4597.30	1	
4471.55	6		4606.54	2	
4473.04	3		4624.84	2	
4475.01	1		4628.10	5	

SPECTRUM OF LANTHANUM.

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4015.44	1		4280.45	2	
4023.79	1		4282.23	1	4282.33 Zr_6
4026.08	2		4287.12	7	
4031.88	6		4296.25	6	
4036.78	1	4036.70 Th_2	4300.62	2	4300.50 Ce_4
4037.44	1		4302.70	1	4302.67 Ca_9
4043.11	8		4316.12	1	
4046.01	3	4045.92 Zr_6	4318.90	1	4318.87 Ca[illegible]
4050.27	5		4334.08	9	
4060.51	1		4335.27	4	
4064.99	1		4354.64	5	
4065.82	1		4363.33	1	4363.32 Ce_2
4067.61	5		4378.04	2	
4076.97	2		4383.70	6	
4077.58	9		4385.45	2	
4077.96	2	4077.91 Sr_{10}	4411.55	1n	
4079.47	1		4419.42	1	
4086.97	10		4423.42	1	
4089.85	1	4089.91 Ce_2	4424.18	1	
4099.73	5		4425.73	1	4425.68 Ca_7
4105.07	1	4105.16 Ce_3	4427.84	5	
4123.46	10		4430.26	8	
4137.21	1		4433.22	2	4433.28 Th_3
4141.95	6		4435.29	1	4435.30 Ca[illegible]
4144.07	1	4144.13 Ce_3	4436.11	1	
4152.17	7	4152.20 Ce[illegible]	4454.98	1	4455.07 Ca_9
4152.99	4		4456.07	2	4456.14 Ca_6
4192.47	5		4522.62	7	
4194.53	1		4525.50	3	
4196.69	6		4526.33	5	
4204.26	4		4554.38	2	4554.42 Ba_{10}
4215.85	2	4215.74 Sr_{10}	4558.72	4	
4217.85	6		4559.57	1	
4227.03	6	4226.89 Ca_{10}	4568.20	1	
4231.26	4		4570.33	1	
4238.67	8		4575.05	4	
4250.26	3		4580.37	2	
4263.76	6		4606.00	2	
4274.27	6		4613.54	4	
4275.82	4		4619.93	4	

The spectrum of lanthanum is characterized by a comparatively large number of *trong* lines.

SPECTRUM OF DIDYMIUM.

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4021.11	1		4262.08	1	
4021.53	1		4262.46	1	
4021.91	1		4266.92	1	
4023.11	1		4272.38	1	
4051.37	1		4272.91	1	
4056.74	1		4275.34	1	
4060.17	1		4280.98	1	
4061.28	3		4284.67	1	
4069.47	1	4069.39 Th_4	4298.01	1	
4075.41	1_n		4303.79	4	
4096.33	1		4304.65	1	
4096.96	1		4306.03	1	4306.04 Zr_3
4100.90	3		4314 66	1	
4109.20	2		4319.18	1	4319.15 Y_2
4109.61	4		4328.19	1	
4110.60	1		4329.21	1	4329.28 Y_2
4113.95	1		4338.94	1	
4116.93	1		4344.61	1	
4124.05	1	4123.95 Ce_7	4351.48	1	4351.51 Y_2
4133.46	1		4358.34	2	
4135.48	1	4135.55 Ce_4	4358.93	1	4358.93 Y_5
4143.08	1	4143.07 Ce_3	4368.53	1	Just
4143.33	2		4368.75	1	separated
4156.29	3		4375.12	4	4375.03 Y_{10}
4164.39	1		4385.85	2	
4165.20	1		4390.86	1_n	
4177.58	3	Double?	4398.17	1	4398.22 Y_6
4178.70	1		4409.02	1	4409.11 Ce_2
4179.56	2_n		4411.29	1	
4185.14	1		4412.47	1	
4289.64	1		4420.74	1	4420.71 Y
4211.57	1	4211.58 Zr_2	4421.39	1	4421.31 Y_2
4223.23	2		4422.83	1	4422.76 Y_5
4225.61	2		4425.51	1	
4232.60	1		4429.45	1	4429.44 Ce_4
4234.55	1	4234.44 Ce_2	4446.57	2	
4235.61	1		4450.09	1	
4236.28	1		4451.79	2_n	
4237.04	1		4456.59	1	4456.50 Zr_2
4240.22	1	4240.14 Ce_5	4463.13	1	4463.22 Y_2
4241.52	1	4241.41 Zr_5	4465.87	1	4465.73 Th_3
4247.65	2		4467.44	1	
4252.66	1		4502.00	1	
4256 65	1	4256.67 Zr_2			

THORIUM.

The carbon electrode was saturated with the nitrate of thorium, and a spectrum of a comparatively large number of lines was obtained, of which, without doubt, a number belong to other metals. The identification of the lines in the spectra of the different metals of the alkaline earths is especially difficult, since the latter cannot be sufficiently separated by chemical methods.

SPECTRUM OF THORIUM.

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4022.30	1	4022.40 Ce_3	4110.98	1	
4025.85	1		4112.43	1	
4026.42	1		4112.92	1	4112.84 Zr_2
4028.94	1		4113.71	1	
4032.74	1_n		4116.83	6	
4034.47	1		4122.02	1	
4036.70	2		4122.83	1	
4041.32	3		4123.70	1	
4043.21	1		4124.76	1	4124.88 Ce_4
4048.22	1		4131.63	2	
4048.61	1		4132.91	4	
4049.02	1_n		4134.21	1	
4069.39	4		4136.51	1	
4073.14	1		4140.35	2	
4077.89	2	4077.91 Sr_{10}	4141.75	2	
4082.03	1	4081.98 Zr_2	4142.63	2	4142.63 Ce_5
4082.43	1	4082.51 Zr_2	4142.80	2	
4085.21	5		4148.31	2_n	
4086.05	1	4085.91 Zr_4	4150.11	3	4150.15 Ce_9
4086.88	3	4086.07 La_{10}	4156.39	1	4156.40 Zr_3
4093.57	1		4156.67	3	
4094.90	4		4159.76	1	
4097.45	1		4162.88	2	Just
4097.85	1		4163.86	2	separated
4099.05	2		4164.45	1	
4100.50	1		4165.24	1	
4100.97	2	4100.90 Di_3	4168.81	2	
4103.35	1		4170.67	1	
4103.75	1		4171.00	1	
4104.47	2		4171.56	2	
4105.46	3		4178.16	5	
4106.03	1		4179.77	2	
4107.50	1	4107.55 Ce_4	4179.98	2	4179.93 Zr_7
4107.93	1		4181.18	1	
4108.55	5		4182.21	1	
4110.31	1		4183.57	1	
4110.70	1		4184.29	1	

SPECTRUM OF THORIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4184.87	1		4344.21	1	
4191.97	1	4192.01 Zr_2	4344.60	1	
4195.73	1	Just	4347.46	1	
4195.97	1	separated	4352.92	1	4352.99 Ce_4
4202.11	1		4353.64	1	4353.71 Ce_2
4206.93	1		4355.54	1	
4209.07	5		4361.52	1	
4211.72	1		4369.48	1	
4215.74	1	4215.74 Sr_{10}	4374.15	1	
4220.27	1		4374.98	2	4375.03 Y_{10}
4226.98	4	4226.89 Ca_{10}	4377.50	1	
4229.73	1		4382.03	5	
4233.51	1		4387.98	1	
4240.84	1	4240.84 Cr_1	4391.29	5	
4244.17	1		4393.31	1	
4248.23	2		4395.14	1	4395.22 Zr_5
4249.91	1		4396.69	1	
4250.57	2		4398.16	1	
4256.34	1	4256.30 Ce_3	4399.39	1	4399.48 Ce_4
4263.54	1		4410.73	1	
4270.50	1		4412.90		Not sufficient-
4271.26	1		4413.02	2	ly divided
4273.51	4		4415.00	1	
4274.17	2	4274.27 La_6	4416.48	1	
4277.04	2		4418.97	1	4418.99 Ce_5
4277.47	4		4426.27	1	
4281.25	1		4427.95	1	
4281.61	1		4433.28	3	
4282.19	6		4435.25	1	4435.30 Ca_x
4283.67	2		4436.56	1	Not sufficient-
4285.16	2n		4436.82	1	ly divided
4286.39	1		4439.42	2	
4288.20	1		4441.21	2	
4295.27	1		4448.14	2	
4298.79	1	4298.80 Zr_2	4455.19	1	
4302.74	1	4302.62 Ca_9	4461.43	1	4461.44 Zr_5
4306.58	1		4465.73	3	
4310.23	2		4474.37	1	
4318.61	1		4476.83	1	
4319.42	1		4483.23	1	
4319.82	1		4487.59	3	
4320.36	1		4510.78	3	
4320.84	1		4531.89	1	
4328.95	1		4532.54	1	
4329.78	1	4329.81 Zr_2	4533.55	1	4533.48 Zr_4
4332.18	1		4537.24	1	
4334.22	1		4554.31	1	
4335.97	2		4555.88	3	
4337.64	2		4563.55	1	
4341.30	1	4341.32 Zr_5	4589.37	1	
4342.50	1	4342.50 Zr_2	4619.60	1	
4343.93	1		4631.70	2	

YTTRIUM.

The spark spectrum of yttrium (chloride) has numerous lines in the violet, of which, however, as the following table shows, a considerable number may belong to other metals, especially lanthanum. From the spectrographic investigation of erbium (chloride) I obtained only such lines as also appear in the yttrium spectrum; it is, however, remarkable that the characteristic and strongest yttrium lines were absent. It may therefore be concluded that the erbium spectrum contains no yttrium lines, and that the lines common to the two spectra are to be removed from the yttrium spectrum. I have designated these lines which are without exception weak by Er ?; however, I do not venture to decide which of them are erbium lines, since no characteristic and strong erbium lines could be observed in the part of the spectrum investigated.

SPECTRUM OF YTTRIUM.

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4032.06	2	λ uncertain, 4031.88	4128.49	4	
4037.63	1	[La_6	4129.59	1	
4040.10	2		4130.57	1	
4041.06	2	Er ?	4134.06	1	
4043.21	2	4043.11 La_5	4137.48	1	
4050.08	1		4137.89	1	
4061.23	2	4061.28 Di_3	4143.01	4	
4073.94	2		4150.16	1	4150.15 Ce_9 [Er ?
4077.56	4	4077.58 La_9	4152.20	2	4152.22 Ce_5 2.17 La_7
4078.12	2		4156.27	2	4156.29 Di_3 Er ?
4083.92	2		4167.76	2	
4085.74	1		4174.41	2	
4086.93	2	4086.97 La_{10} Er ?	4177.81	10	
4098.78	2	Er ?	4179.73	1	4179.77 Th_2
4100.94	1	4100.90 Di_3 0.97 Th_2	4184.46	1	
4102.56	5		4186.87	2_n	
4103.50	2		4189.83	1_n	
4109.63	2	4109.61 Di_4 Er ?	4195.03	1	4195.00 Zr_5
4110.88	1	4110.88 Zr_2 Er ?	4196.63	1	4196.60 La_{10}
4111.57	1	4111.51 Ce_3 Er ?	4203.10	1	4203.18 Ce_5
4112.23	1		4204.84	4	
4114.03	1		4206.81	1	
4123.42	2	4123.46 La_{10} Er ?	4212.02	2	4212.17 Zr_7
4124.05	1	Er ?	4220.85	1	
4125.09	3		4223.14	1	4223.22 Di_2

SPECTRUM OF YTTRIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4225.60	2		4378.49	1	
4226.98	4	4226.89 Ca_{10} Er?	4382.27	1	4382.38 Ce_5
4229.93	1		4385.86	2	Er?
4232.62	1		4387.01	1	4387.04 Ce_5
4235.94	3		4387.86	1	4387.70 La_6
4236.92	1	4236.89 Zr_5	4391.08	2	Er?
4238.62	1	4238.67 La_8 Er?	4391.91	1	4391.93 Ce_5 Er?
4240.10	1	4240.14 Ce_5	4398.22	6	4398.22 Th_6
4251.98	1		4401.08	1	4401.09 Ce_2
4252.68	1		4403.46	1	
4253.75	1	4253.76 Zr Er?	4409.11	1	4409.11 Ce_2
4256.60	2		4409.63	2	
4262.25	1		4411.28	1	
4262.90	1		4418.99	1	4418.99 Ce_5
4263.74	1	4263.76 La_6	4419.79	1	
4272.00	1	4271.94 Ce_4	4420.71	2	4420.65 Zr_3 Er?
4279.84	2		4421.31	2	Er?
4280.93	2	Er?	4422.77	5	
4284.66	1		4424.50	2	Er?
4285.69	1		4429.49	1	Er?
4287.12	1	4287.12 La_7	4430.13	2	4430.26 La_8 Er?
4290.12	1	4290.16 Ce_6 Er?	4434.18	2	
4296.28	1	4296.25 La_6	4434.62	2	Er?
4296.94	1	4296.90 Ce_8 6.86 Zr_6	4434.99	1	
4302.67	2	4302.62 Ca_9 Er?	4443.94	1	4443.98 Ce_2 Zr_2
4306.20	2		4444.52	2	4444.48 Vd_4
4309.85	9		4449.65	1	4449.59 Ce_5
4314.74	1		4450.05	1	
4319.15	2	Er?	4450.99	1	4450.94 Ce_4
4327.37	1		4451.79	2	
4328.26	1		4452.93	2	
4329.28	2	Er?	4454.97	2	4455.07 Ca_9 Er?
4331.02	1		4458.75	2	Er?
4331.50	2		4460.45	2	4460.52 Ce_6 Er?
4334.35	2	4334.08 La_9 Er?	4463.22	2	Er?
4339.25	1		4465.68	2n	Double? 4465.73 Th_3
4341.63	1		4467.19	2	
4342.45	2		4469.57	1	Er?
4346.77	1	4346.81 Zr_2	4471.26	1	
4348.08	2		4473.06	1n	Double? 4473.04 Ce_3
4349.01	2		4477.19	1	
4351.51	2		4477.66	1	
4352.22	1		4478.89	1	
4358.93	5		4487.66	2	4487.59 Th_3
4361.02	1	4361.07 Zr_3	4506.12	2	
4362.33	1		4519.74	2	
4364.41	1		4522.49	1	4522.62 La_7
4364.96	1	4364.91 Ce_4	4523.18	1	
4366.38	1		4524.00	1	
4368.81	1		4527.34	2	4527.30 Ce_4 Er?
4375.03	10		4527.93	2	Er?

ZIRCONIUM.

This metal could be obtained in crystalline laminæ, which were, however, very small and fragile. A few pieces were found which it was possible to use as electrodes.

These laminæ quickly disintegrated in the induction spark, and in view of the rich and interesting spectrum I would gladly have used more compact pieces; such, however, were not to be had.

SPECTRUM OF ZIRCONIUM.

Wave length tenth-meters	Intensity		Wave length tenth-meters	Intensity	
4018.56	4		4078.51	3	
4024.20	3		4081.38	0	
4024.66	6		4081.98	2	
4025.13	4		4082.51	2	
4027.42	4		4083.28	2	4083.38 Ce_6
4029.19	3		4084.48	3	
4029.85	7		4085.91	4	
4030.21	4		4087.88	2	
4031.58	2	4031.46 Ce_4	4090.68	0	Beautiful
4032.25	2		4090.97	3	double line
4034.34	3		4093.40	1	
4036.10	4		4094.48	2	
4040.46	3		4096.85	4	
4041.82	2		4099.52	2	
4042.45	3		4107.73	3	
4043.78	4		4108.59	3	4108.55 Th_3
4044.76	4		4110.19	3	
4045.92	6	4045.97 Ce_5	4110.85	2	
4048.78	8		4112.19	2	
4050.46	6		4112.84	2	
4054.54	2		4114.55	2	
4055.16	5		4119.38	2	
4055.84	4		4119.92	2	4119.94 Ce_7
4056.60	2		4120.32	2	
4057.94	2		4121.55	5	4121.52 Ce_6
4058.80	2		4128.08	2	4128.19 Vd_3
4060.32	2		4133.19	n	4133.05 Ce_5
4060.72	2		4135.88	3	
4061.66	3		4140.22	2	
4064.31	6		4146.12	n	
4068.93	2	4068.96 Ce_4	4147.94	2	
4071.26	3		4149.45	10	
4072.89	6		4151.18	8	
4075.14	4		4152.89	4	4152.99 La
4076.74	3		4156.49	5	
4077.25	3		4161.45	6	

SPECTRUM OF ZIRCONIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4163.98	n		4287.54	2	
4166.51	4		4289.33	2	
4169.49	2		4289.94	1	4289.82 Ce_7
4171.63	2	4171.75 Ur_3	4290.45	2	
4179.93	7		4291.20	2	
4183.43	3		4291.53	3	
4186.83	6	4186.70 Ce_8	4293.35	5	
4187.67	6		4294.98	5	
4191.77	2		4295.98	2	
4192.01	2		4296.86	6	4296.90
4194.23	2		4298.80	2	
4195.00	5		4300.04	2	
4196.43	3	4196.54 Ce_5	4300.66	2	
4199.34	5		4301.21	2	
4201.71	5		4301.96	5	
4206.20	2		4302.99	5	
4209.23	10		4304.82	3	
4210.92	3		4306.04	3	
4211.58	2		4309.11	3	
4212.17	7		4309.96	2	4309.85 Y_4 .93 Ce_4
4212.95	2		4312.38	2	
4214.15	5		4313.08	2	
4227.99	7		4315.10	5	
4231.88	6		4317.47	5	
4234.90	4		4319.21	2	
4236.37	5		4319.82	n	
4236.89	5		4321.28	2	
4237.72	3		4322.81	2	4322.74 La_5
4239.60	6		4324.17	2	
4240.57	5		4325.63	5	
4241.41	5		4329.81	2	
4241.99	6		4333.46	5	
4253.76	2		4336.55	n	4336.54 Ce_3
4254.55	2	4254.61 Cr_9	4337.91	4	4338.08 Ce_5
4256.67	2		4339.74	2	4339.73 Cr_4
4258.22	7		4341.32	5	
4261.47	2		4342.50	2	
4261.67	2		4343.39	2	
4263.36	2		4343.69	2	
4264.33	2		4345.32	n	
4265.13	2		4345.90	n	
4266.97	2		4346.81	2	
4268.19	5		4347.47	n	
4273.68	6		4348.22	6	
4274.92	3	4274.95 Cr_8	4359.01	2	4358.93 Y_5
4276.86	2		4360.01	9	4359.86 Cr_4
4277.50	2	4277.47 Th_4	4361.07	3	
4282.33	6		4366.63	4	
4285.46	n	4285.53 Ce_4	4371.17	7	
4286.20	2		4373.27	2	
4286.71	3		4379.98	8	

SPECTRUM OF ZIRCONIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4389.72	2		4491.75	2	
4390.68	2		4494.75	6	
4391.12	2	4391.29 Th_5	4495.69	2	
4395.22	5		4497.22	8	
4400.42	2		4501.47	2	
4401.54	2		4504.23	2	
4403.63	5		4507.33	4	
4413.24	3		4512.98	2	
4414.75	4		4518.26	2	
4420.65	3		4520.49	2	
4426.26	n		4523.00	2	
4427.49	3		4526.33	2	4526.33 La_5
4429.34	2	4429.44 Ce_4	4527.58	2	
4429.53	2		4531.35	2	
4431.74	3		4533.48	4	
4436.16	1		4534.19	2	
4437.09	1		4535.00	3	
4438.33	2		4535.98	6	
4440.72	5		4540.11	2	
4443.25	9		4542.37	4	
4443.98	2		4544.89	2	
4447.34	n		4548.98	2	
4449.31	2		4549.81	4	
4450.49	2		4552.58	1	
4451.12	2		4553.23	3	
4453.52	2		4554.24	5	
4453.89	5		4555.30	3	
4455.00	2	4455.07 Ca_9	4555.63	3	
4455.59	2		4558.23	2	
4456.50	2		4562.35	2	
4457.66	5		4564.04	2	
4460.57	2		4565.64	3	
4461.44	5		4572.24	2	
4467.13	2		4574.78	4	
4468.69	?		4575.73	4	
4469.70	2		4582.50	2	
4470.72	5		4590.66	2	
4480.95	3		4596.39	2_n	
4481.58	2		4602.70	4	
4482.56	3_n		4604.49	2	
4484.45	2_n		4614.07	4	
4485.76	2		4621.53	3_n	
4488.55	2		4626.42	3	
4489.38	2		4629.12	5	
4490.53	2		4633.91	4	

VANADIUM.

In this case a blue-green aqueous solution of vanadium chloride, with which the carbon electrodes were saturated, was used, since I could not obtain metallic venadium in suitable pieces. Hasselberg is at present engaged in an investigation of this metal, of which he received a piece fused in the electrical furnace of Moissan in Paris. He found that the mineral rutile, which he used in obtaining the spectrum of titanium, contains vanadium, and gives in a preliminary publication[1] the wave-lengths of a number of vanadium lines in the violet, which I have included in the following table:

SPECTRUM OF VANADIUM.

Wave-length tenth-meters	Intensity		Wave-length (Hasselberg) tenth-meters	Wave-length tenth-meters	Intensity		Wave-length (Hasselberg) tenth-meters
4023.64	1			4120.63	1		
4035.86	1	4035.91 Mn_6		4123.60	3		4123.68_3
4051.15	1			4128.19	3		$4128.20_{3\cdot4}$
4051.53	1	4051.54 Ce_2		4132.16	4		
4057.28	1			4159.91	1		$4159.79_{2\cdot3}$
4064.12	1			4174.20	1		
4071.68	1			4179.57	1		4179.56 Di_2
4077.86	3	4077.91 Sr_{10}		4181.05	1		
4090.69	2	4090.68 Zr_6	4090.73_3	4182.70	1		
4092.63	1	4092.54 Ce_5		4183.56	1		$4183.45_?$
4092.81	3	4092.87 W_4	4092.83_3	4190.00	1	4190.09 Mn_2	
4095.59	2		4095.65_3	4202.55	1		
4099.90	1		$4099.94_{3\cdot4}$	4205.26	1		
4102.26	1			4210.07	1	4210.06 Cr_2	
4104.43	1	4104.47 Th_2		4215.77	3	4215.74 Sr_{10}	
4104.89	1	4104.80 Co_2		4225.52	1		
4105.27	4		4105.31_3	4226.98	7	4226.89 Ca_{10}	
4108.31	1			4232.74	2		
4109.85	4		$4109.92_{3\cdot4}$	4233.20	1		
4110.04	6			4234.26	1		
4110.25	1			4234.79	1		
4112.39	1			4257.56	1		
4113.59	1			4259.55	1		
4115.26	4		$4115.32_{3\cdot4}$	4262.36	1		
4116.57	3		4116.64_3	4268.85	2		4268.85_3
4118.31	1	4118.24 Ce_6		4271.76	2		4271.80_3
4119.53	1			4277.17	2		

[1] "Ueber das Vorkommen des Vanads in den skandinavischen Rutilarten." Stockholm, 1897. Also *Ap. J.*, 5. 194.

SPECTRUM OF VANADIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length (Hasselberg) tenth-meters	Wave-length tenth-meters	Intensity		Wave-length (Hasselberg) tenth-meters
4283.17	1	4283.19 Ca$_7$		4420.14	1		
4284.24	2			4421.79	3		
4286.63	1			4422.47	1		
4288.02	1	4288.12 Ur$_2$		4423.41	1		
4289.57	1	4289.51 Ca$_6$		4424.15	1		
4292.05	2			4424.81	1		
4296.34	1			4425.73	1	4425.68 Ca$_7$	
4297.94	1			4426.26	3		
4298.30	1			4428.77	2		
4299.21	1	4299.16 Ca$_5$		4430.09	2		
4302.79	3	4302.62 Ca$_9$		4434.92	1		
4303.87	1	4303.77 Ce$_2$		4435.18	2	4335.30 Ca$_8$	
4306.44	1			4436.04	1	4335.99 Ca$_7$	
4307.44	1			4436.45	3	4336.57 Mn$_5$	
4308.06	1	4307.91 Ca$_7$		4438.14	4		
4310.03	1	4309.93 Ce$_4$		4441.96	4		
4318.91	1	4318.87 Ca$_7$		4443.61	1		
4330.32	3			4444.48	4		4444.41_{3-4}
4333.11	3		4330.15_3	4449.84	1		
4341.32	4	4341.32 Zr$_5$	4333.00_3	4451.28	1		
4343.14	1		4341.15_3	4452.29	4		
4353.14	5			4455.01	2	4455.07 Ca$_9$	
4355.30	1		4353.01_{3-4}	4456.11	2	4456.14 Ca$_6$	
4356.21	1			4456.82	1		
4363.79	1			4457.70	2	4457.73 Mn$_5$	
4364.45	1			4457.92	1		
4368.23	1			4460.02	5		
4368.80	1			4460.55	6		
4373.45	1	4373.44 Cr$_2$		4461.26	1	4461.24 Mn$_5$	
4374.04	1	4374.01 Ce$_3$		4462.62	3		
4375.50	1	4375.49 Cr$_2$		4465.79	1	4465.73 Th$_3$	
4379.39	8			4468.23	1		
4380.71	1		4379.40_{4-5}	4469.00	1		
4381.28	1			4469.92	3		
4384.89	7			4474.23	1		
4390.16	6		4384.85_{4-5}	4474.93	2		
4392.27	1		4390.11_{4-5}	4480.30	1		
4393.28	1			4489.06	2		
4394.06	1			4490.32	1		
4395.42	5			4490.95	1	4491.01 Ur$_2$	
4400.79	4		4395.40_4	4496.25	1		
4403.92	1			4496.93	1	4497.06 Cr$_3$	
4406.42	1			4502.11	1		
4406.86	6	Beautiful	4406.85_{4-5}	4514.23	1		
4407.83	6	group of	4407.85_{4-5}	4524.28	1		
4408.44	5	lines	4408.39_4	4529.64	1		
4408.72	5		4408.70_{4-5}	4530.93	1		
4412.34	1			4545.63	2		
4416.66	3		4416.70_3	4549.90	1	4580.81 Zr$_4$	

SPECTRUM OF VANADIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length (Hasselberg) tenth-meters	Wave-length tenth-meters	Intensity		Wave-length (Hasselberg) tenth-meters
4553.37	1			4580.63	3		
4554.29	3	4554.24 Zr_5		4586.62	3		
4560.99	1			4591.57	1	4591.57 Cr_2	
4572.06	1			4594.43	3		
4577.42	2			4606.48	1	4606.54 Ce_2	
4578.92	1			4619.87	1	4619.93 La_4	

URANIUM.

In the case of this very refractory metal I also made use of the chloride, which is soluble in water. Strong lines were not obtained in the violet part of the spectrum, but a considerable number of fine, sharp lines.

SPECTRUM OF URANIUM.

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4017.67	2		4117.75	1	4117.70 Ce_3
4019.11	1	4019.18 Ce_3	.4124.93	2	4124.88 Ce_4
4026.16	2		4128.54	2	4128.49 Y_4
4033.59	1		4133.40	1	
4033.88	1	4033.80 Mn_2	4133.76	1	
4042.60	1		4135.98	1	
4042.91	2		4138.86	1	
4044.60	2		4139.34	1	
4050.24	2	4050.27 La_5	4141.44	2	
4052.11	2		4162.01	1	
4053.23	1		4162.74	1	
4054.51	1	4054.54 Zr_2	4163.87	2	4163.82 Cr_3
4058.38	2		4164.97	1	
4062.76	2		4165.82	2	4165.73 Ce_7
4067.97	2		4169.23	1	
4071.33	2	4071.26 Zr_3	4171.75	3	
4088.49	2		4173.12	2	
4090.08	3		4174.35	2	
4091.46	2		4189.37	2	
4097.97	2		4197.64	2	
4106.51	2		4204.54	1	
4107.10	1	4107.02 Ce_2	4206.61	1	
4116.27	2		4211.84	1	
4117.10	1	4117.10 Ce_3	4212.42	1	

SPECTRUM OF URANIUM—*continued.*

Wave-length tenth-meters	Intensity		Wave-length tenth-meters	Intensity	
4214.01	1		4362.40	2	
4214.59	1		4363.01	2	
4215.76	2	4215.74 Si_{10}	4372.74	2	
4223.02	1		4373.59	2	
4226 96	4	4226.89 Ca_{10}	4393.81	2	
4228.96	2		4402.70	1	
4231.41	1		4406.07	1	
4231.91	1	4231.88 Zr_6	4406.72	1	
4232.24	1		4420.76	1_n	4420.71 Y_2
4234.85	1	4234.90 Zr_4	4423.28	1	
4240.84	1		4423.91	1	
4241.89	4	4241.99 Zr_6	4425.57	1	4225.68 Ca_7
4243.41	1_n		4426.87	1	
4244.58	3		4427.84	2	4427.84 La_5
4252.60	2		4434.11	2	
4267.44	2		4434.74	2	
4269.73	2		4435.84	1	
4274.06	1		4437.07	1	
4276.69	2		4450.83	1	
4278.35	1		4455.14	1	4455.07 Ca_9
4282.25	2		4463.06	2	
4283.28	1	4283.19 Ca_7	4465.38	2	
4288.12	2	4288.21 Ni_3	4472.61	3	
4289.09	1		4477.90	2_n	
4290.11	2	4290.16 Ce_6	4486.53	1	
4291.08	2		4491.01	2	
4295.60	1		4491.71	1	4491.75 Zr_2
4297.35	2		4493.28	1	
4301.91	2	4301.96 Zr_5	4506.33	1	
4302.71	2	4302.62 Ca_9	4510.51	2	
4310.55	1		4511.83	1	4511.86 Jn_{10}
4312.80	1		4515.48	2	
4313.34	1		4521.79	1	
4314.05	2		4538.42	2	
4323.95	1		4543.87	2	
4324.87	1		4545.77	2	
4327.20	1		4554.14	1	
4335.96	1		4555.28	1	4555.30 Zr_3
4336.70	1		4567.80	1	
4341.92	3		4570.14	1	
4347.37	2_n		4573.91	1	
4354.68	2_n	4354.64 La_5	4603.80	2	
4355.84	2		4605.31	2	
4357.92	1		4627.08	2	
4361.34	1		(4646.32)	2	λ uncertain

ON THE CONDITIONS OF MAXIMUM EFFICIENCY IN ASTROPHOTOGRAPHIC WORK.

PART I. GENERAL THEORY OF THE TELESCOPIC IMAGES OF DIFFERENT FORMS OF RADIATING SOURCES.

By F. L. O. Wadsworth.

The theoretical relations between aperture and focal length of an objective and the intensity of the images of celestial objects at its focal plane, have been discussed by a large number of different writers, among others Angot,[1] E. C. Pickering,[2] Grubb,[3] Harkness,[4] Searle,[5] Newall,[6] and W. H. Pickering.[7] All of the writers whose papers I have been able to examine have, with the exception of Angot and Newall, treated the subject from the standpoint of geometrical optics, and all of them without exception have failed to consider the influence of the aperture upon the intensity of the illumination at the focal plane due to the general (diffused) light of the sky. In regard to the method of treatment, I have already pointed out in previous articles[8] that geometrical considerations alone are almost certain to lead one to very erroneous conclusions (as has been the case with more than one writer of reputation in the case of the spectroscope), particularly when

[1] "Étude sur les Images Photographiques obtenues au foyer des Lunettes Astronomiques," *M. N.*, **37**, 387, May 1897.

[2] "An Investigation in Stellar Photography," *Mem. Amer. Acad. Sci.* **10**, 179, 1886.

[3] "On the Choice of Instruments for Celestial Photography," *M. N.*, **47**, 309, April 1887.

[4] "Astronomical Photography with Commercial Lenses," *Astronomy and Astrophysics*, **11**, 641, Oct. 1892.

[5] "Probable Advantages in Astronomical Photography of Short Focus Lenses," *Ibid.*, **12**, 575, Aug. 1893.

[6] "On the Formation of Photographic Star Disks," *M. N.*, **54**, 515, June 1894.

[7] "Investigations in Astronomical Photography," *Ann. Harvard College Obs'y*, **32**, Part I, 1895.

[8] See paper "General Conditions respecting the Design of Astronomical Spectroscopes," *Ap. J.*, **1**, 52, Jan. 1895; also paper "Further Notes on Astronomical Spectroscopes," *ibid.*, **3**, 176, March 1896; and "Conditions of Maximum Efficiency in the Use of the Spectrograph," *ibid.*, **3**, 321, May 1896.

dealing with sources of light of negligible angular magnitude, such as the stars, the smaller satellites and asteroids, and stellar nebulæ. In the present case the general failure to make use of the methods of physical rather than of geometrical optics is perhaps responsible for the oversight of the relations between intensity of general field and aperture, just alluded to.

The importance of this relation will be at once evident when it is remembered that the faintest image that can be either visually observed or photographically delineated on the sensitive plate must be somewhat brighter than the general field; and that it is, therefore, this *degree of contrast* between image and field rather than the *size* of the objective (except in so far as this latter influences the contrast) that determines the limiting magnitude of the faintest star or nebular detail that can ever be photographed.[1]

It becomes, therefore, of the greatest importance to define accurately the *relative* intensities of the images; I, of point sources (stars, asteroids, etc.), and II, of sources of finite though limited extent (nebulæ, comets, planets, etc.), in comparison with, III, extended luminous surfaces, such as the sky, which form the background against which, I and II, are seen or photographed. The expressions for all three cases are easily derived from fundamental considerations of the wave-theory, and have been for a long time well known. But in view of the considerable confusion of ideas that still seem to exist in regard to I and II (particularly I), and in view of the fact that the influence of III, seems to have been entirely lost sight of, it may be excusable to briefly outline the principal steps in the derivation of the expressions for the intensity of the physical images of point, line, and surface sources

1. The image of a mathematical point of unit brightness as seen from the image forming lens, and emitting monochromatic light of wave-length λ is a diffraction pattern whose center is coincident in position with the geometrical image, and whose intensity is represented by the general expression[2]

[1] "On the Conditions which determine the Limiting Time of Exposure for Photographic Plates in Astronomical Photography." *Knowledge*, Aug. and Sept. 1897.

[2] See Rayleigh, "Wave Theory," *Enc. Brit.*, 24, §§ 11 and 12.

$$I_1^2 = \frac{1}{\lambda^2 f^2}\left[\int\int \sin\left(\frac{2\pi\xi}{\lambda f}x_1 + \frac{2\pi\eta}{\lambda f}y_1\right) dx_1\, dy_1\right]^2 + \frac{1}{\lambda^2 f^2}\left[\int\int \cos\left(\frac{2\pi\xi}{\lambda f}x_1 + \frac{2\pi\eta}{\lambda f}y_1\right) dx_1\, dy_1\right]^2, \quad (1)$$

where f is the focal length of the image forming lens; ξ, η, the coördinates of a point in the diffraction pattern referred to its center (position of geometrical image); and x_1, y_1 the coördinates of a point in the diffracting aperture; the integration being extended over the whole of this aperture. If the latter is symmetrical with respect to x_1 and y_1, the first integral disappears ($\sin x$ being an uneven function), and the expression for I_1^2 reduces to the form

$$I_1^2 = \frac{1}{\lambda^2 f^2}\int\int \cos\frac{2\pi\xi}{\lambda f}x_1 \cos\frac{2\pi\eta}{\lambda f}y_1\, dx_1\, dy_1. \quad (1a)$$

Under these conditions the diffraction pattern is also symmetrical about the origin of coördinates, and if the aperture is circular, as is generally the case with a telescope, the intensity along the axis ξ is the same as along any other radial line r. Replacing ξ by r and integrating with respect to y along the ξ axis ($\eta = 0$), we at once obtain the second integral in the form

$$2\int_{-\frac{b}{2}}^{+\frac{b}{2}} \sqrt{\left(\frac{b}{2}\right)^2 - x_1^2}\, \cos\frac{2\pi r}{\lambda f}x_1\, dx_1$$

b being the diameter of the object glass.

By putting $x_1 = \frac{bw}{2}$ and $\frac{\pi b}{f\lambda}r = n$, we have for I_1^2

$$I_1^2 = \frac{1}{16}\frac{\pi^2 b^4}{\lambda^2 f^2}\left[\frac{4}{\pi}\int_0^{+1}\sqrt{1-w^2}\cos nw \,.\, dw\right]^2 = M \,.\, [\phi(n)]^2, \quad (2)$$

which is the form first obtained and computed by Airy.[1]

Similarly, by putting $x_1 = \frac{b}{2}\cos\phi$, we obtain

$$\left.\begin{aligned} I_1^2 &= \frac{1}{16}\frac{\pi^2 b^4}{\lambda^2 f^2}\left[\frac{2}{\pi}\int_0^{+\pi}\cos\left(\frac{\pi b}{\lambda f}r\cos\phi\right)\right]\sin^2\phi \,.\, d\phi \\ &= M \,.\, \frac{4 J_1^2(Br)}{(Br)^2} = M \,.\, 4\, z^{-2} J_1^2(z) \end{aligned}\right\} \quad (3)$$

where $J_1(z)$ is Bessel's function of order unity.

[1] "On the Diffraction of an Object Glass with Circular Aperture," *Camb. Phil.*

This last (3) is the form due to Lommel,[1] who first applied Bessel's functions to the diffraction integrals.[2] These expressions represent, as is well known, the curve shown in Fig. 1 which

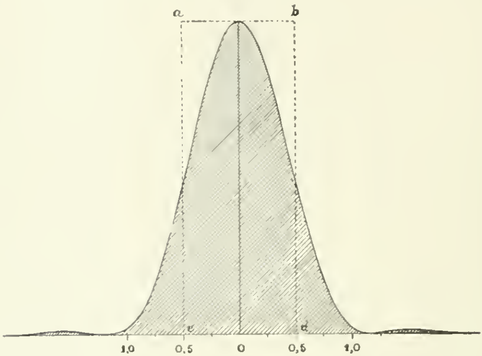


Fig 1

has been plotted from the values of $4 z^{-2} J_1^2(z)$ given by Lommel.[3] The whole diffraction pattern is the symmetrical ring system

Trans., 1834; also "Undulatory Theory of Optics," 2d ed., 1877, pp. 78–80, and Table II, p. 159.

[1] *Lommel*, "Studien über die Besselschen Functionen," Leipzig, 1868; and *Z. f. Math. u. Phys.*, 15, 166, 1870. See also Rayleigh, "Wave Theory," *Enc. Brit.*, 24, § 12.

[2] My attention is called in this connection to an apparent blunder in one of my previous papers (*Ap. J.*, 1, 57, line 10), due to the inadvertent omission of the words "*each point in*." The sentence in question should read "If the aperture is circular the diffraction image of each point in a vertical line (the bounding edge of the slit for example), etc. Strictly speaking, I *ought* to have made use of the expression for the diffraction image of a *line* instead of a point, in the case there considered. I did not do so, however, for the reason that for a circular aperture the former is much more complicated and less easily calculated (for plotting) than the latter, while the distribution in intensity (in a direction at right angles to the line) is so nearly the same in the two cases that the results arrived at (with reference to the effective broadening of a slit image by the effects of diffraction at the edges) would have been practically the same in the end. If the aperture is rectangular, as is generally the case in a spectroscope, they would be exactly the same.

[3] *Loc. cit.*

which would be obtained by revolving the figure about the axis of symmetry through the center o.

The lateral dimensions of the pattern vary as $\frac{\lambda f}{b}$, *i.e.*, the first minimum (dark ring) occurs at the point

$$r_1 = 1.22\frac{\lambda f}{b} = 1.22\frac{\lambda}{\beta}.$$

It is evident from either of these expressions that the intensity of illumination in the image of a point will depend on two things of an entirely different nature. *A*. On the brightness and character of the source of radiation. *B*. On the dimensions *i.e.*, aperture and focal length, of the image forming lens. It is not our purpose to deal with the first cause of variation at any length in this paper, which will concern itself chiefly with the effect of variations in the dimensions of the observing instrument under the different conditions met with in astrophotographic work. It may, however, be well for the sake of completeness, to briefly indicate the character of the various effects produced by variations of the first character, which as far as I have been able to find, have never before been considered, and indicate their bearing on some important problems in stellar photometry and stellar measurement, which will be considered more at length in subsequent papers.

A. *Effect of variations in the value of* λ.—If the light from the source of radiation were absolutely monochromatic, the intensity of the image would vary inversely as the square of the wave-length, a result due to the contraction of the linear dimensions of the pattern in the ratio of the first power of λ (see Fig. 1). But in general the radiation from any physical point, such as a star, is heterogeneous, the wave-length of the radiations ranging (theoretically at least) from 0 to ∞. The diffraction pattern resulting from the superposition of the individual images formed by the light of each wave-length λ, will be found by multiplying (2) or (3) by a factor, $\psi(\lambda)$ which expresses the distribution in intensity in the normal spectrum of a star as a function of the wave-length and integrating with respect to λ from 0 to ∞.

This gives us

$$I_R^2 = \int_0^\infty \psi(\lambda)\, I_1^2\, d\lambda\,. \tag{4}$$

The expression I_R^2 represents the distribution in intensity in what may be termed the *real* diffraction image of a radiating point as formed at a focus of a perfectly achromatic telescope (for example, a perfectly figured reflector) of circular aperture and having the same coëfficient of transmission or reflection for radiations of all wave-lengths. In general neither the conditions of perfect achromatism not that of perfect equality of transmission will be fulfilled. In the first case the function I_1^2 would take the form[1]

$$I^2 = \frac{1}{e^2}\left[U_1^2 + U_2^2\right],$$

where

$$U_1 = \frac{eb}{fr} J_1(z) - \left(\frac{eb}{fr}\right)^3 J_3(z) + \ldots\ldots \tag{5}$$

and

$$U_2 = \left(\frac{eb}{fr}\right)^2 J_2(z) - \left(\frac{eb}{fr}\right)^4 J_4(z) + \ldots\ldots,$$

where e is the difference (measured towards the object glass), between the principal focal plane (at distance f from the object glass), and the focal plane for the radiation of wave-length λ. In the second case the function $\psi(\lambda)$ would simply have to be multiplied by a factor k_λ representing the coëfficient of transmission or reflection for each wave-length λ. Introducing this factor and reducing to the simplest form (r being constant as respects the integration for λ), we would have in the case of the achromatic objective from (3),

$$I_R^2 = \frac{b^2}{4r^2}\int_0^\infty k_\lambda \,.\, \psi(\lambda) \,.\, J_1^2\left(A\frac{r}{\lambda}\right) d\lambda\,. \tag{6}$$

The results obtained from the integration of (6) for different values of $\psi(\lambda)$ are of great interest in connection with the problem of measuring stellar temperatures. For since I_R^2 is a function of $\psi(\lambda)$, which represents the distribution of intensity in the

[1] LOMMEL, *Abhand. d. K. Bayer. Akad.*, 15. 235, 1880.

spectrum of the radiating point, and since this again is a function of the temperature of that point, it follows that a measurement of the distribution of intensity in the real diffraction image would afford us a means of measuring directly the temperature of the stars. At present we have no telescope large enough and no instruments sensitive enough to enable such measurements to be made ; but in view of the rapid progress in both of these directions during the last few years, it does not seem altogether improbable that before long such a method of investigation may become possible and practicable. The theoretical side of this problem will be discussed more at length in a paper which is now in course of preparation.[1]

A (*b*). In the case of visual observations what we are concerned with is not the distribution in intensity in the *real* diffraction image represented by (4) or (6), but the *effective* distribution in intensity as regards the eye. This will be obtained by integrating (4) only over that range of wave-lengths to which the observer's eye is sensitive. But since this sensitiveness is very different for different wave-lengths and is also relatively different for different observers, we must before integration introduce another factor, $L(\lambda)$, the ordinate to the "luminosity curve" for that particular observer. We then obtain

$$I_L^2 = \int_{\lambda_2}^{\lambda_1} k_\lambda \cdot \psi(\lambda) \cdot L(\lambda) \cdot I^2 \cdot d\lambda \tag{7}$$

which for the case of the achromatic objective becomes, as before,

$$\frac{b^2}{4r^2} \int_{\lambda_2}^{\lambda_1} k_\lambda \cdot L_\lambda \cdot \psi(\lambda) \cdot J_1^2\left(A\frac{r}{\lambda}\right) \cdot d\lambda \,. \tag{7a}$$

These integrals will be further considered in connection with the problem of determining the angular magnitudes of the stars from micrometrical measurements of the diameters of their diffraction rings, the elementary theory of which has already been developed by the writer.[2]

[1] "On a Method of Determining the Temperature of a Radiating Point from the Study of its Diffraction Pattern at the Focus of a Telescope," to be published in a future number of this JOURNAL.

[2] See paper "On the Resolving Power of Telescopes and Spectroscopes for Lines

A (*c*). In the case of photographic work we are similarly concerned with the *effective* distribution in intensity in the diffraction image with reference to the sensitive plate. As in the case of the eye, this will be obtained by introducing in (4) a factor P_λ (of the same nature as $L(\lambda)$), which represents the varying ordinate of the "actinic" curve for the particular kind of photographic plate which is being used, and integrating the resulting expression between the limiting wave-lengths λ_3 and λ_4, to which the plate is sensitive. This gives us

$$I_P^2 = \int_{\lambda_4}^{\lambda_3} k_\lambda \cdot P_\lambda \cdot I^2 \cdot d\lambda, \qquad (8)$$

the value of I^2 being taken, as before, from either (3) or (5), according as the objective is or is not perfectly achromatic. This integral is of great importance in connection with the problem of the photographic determination of stellar magnitudes. At present these determinations are based on purely empirical formulæ, whose constants are determined by measurement of the photographic images of certain stars whose magnitudes have been determined by a different (*visual*) method. These formulæ are, therefore, only applicable to a (usually) very limited number of cases, and a more general formula derived from (8) and, therefore, based upon well-established theoretical considerations would, therefore, seem to possess certain very important advantages. It at least offers a logical explanation of the growth of the photographic image, which has been attributed, heretofore, to such manifestly inadequate causes as halation, photographic radiation, residual spherical aberration, etc. Further consideration of this subject is reserved for a future paper.

The integrals I_L^2 and I_P^2, (7) and (8), represent the distribution in intensity in what may be termed respectively (in contradistinction to the term used in connection with I_K^2) the "visu-

of Finite Width," *Mem. Spettr. Ital.*, **26**, 1, footnotes on pp. 6 and 7; *Phil. Mag.*, **43**, 317, footnotes on pp. 323 and 324. *Wied. Ann.*, **61**, 604, footnotes pp. 611 and 612. See also paper there referred to, "Application of Interference Methods to Astronomical Measurements," *Phil. Mag.*, **30**, 1, pp. 14 to 17. This theory will soon receive fuller consideration.

ally effective" and the "photographically effective" diffraction images.

Our knowledge of the individual functions k_λ, $\psi(\lambda)$, $L(\lambda)$, and $P(\lambda)$, which appear in (7) and (8), is unfortunately very limited. But for the purpose of integration we only need to know the products of the three functions

$$F_1(\lambda) = k_\lambda \cdot L(\lambda) \cdot \psi(\lambda), \tag{9}$$

and

$$F_2(\lambda) = k_\lambda \cdot P(\lambda) \cdot \psi(\lambda). \tag{10}$$

From the experiments of Abney,[1] Langley,[2] and others we can obtain $F_1(\lambda)$ and $F_2(\lambda)$ for various cases which correspond closely to those ordinarily met with in practice. These various cases will be considered more in detail in connection with the development of cases A, A (b), A (c), outlined above.[3]

B. Variations in the intensity of the image (I_1^2) *due to variations in the aperture and focal length af the observing instrument.*— Since not only the intensity but also the breadth of the diffraction pattern represented by (2) and (3) changes with the aperture b of the telescope, we must, in considering the relative brightness of the images given by two different instruments, fix upon some one point in the image as a basis of comparison, most conveniently its center (the position of the geometrical image). At this point $r = 0$, and

$$\phi(o) = 4\frac{J_1^2(o)}{o} = 1,$$

hence

$$i^2 = \frac{1}{16} \cdot \frac{\pi^2 b^4}{\lambda^2 f^2}. \tag{11}$$

Considering λ as constant (for its value take the mean wave-

[1] "On the Effect of the Spectrum on the Haloid Salts of Silver," *Proc. R. Soc.*, **33**, 164, 1881; "On the Comparative Effects of Different Parts of the Spectrum on Silver Salts," *Ibid.*, **40**, 251, 1886; "On Color Photometry," *Phil. Trans.*, **177**, 1886; "Transmission of Sunlight through the Earth's Atmosphere," *Ibid.*, **178**, 1887; etc., etc.

[2] "Energy and Vision," *Nat. Acad. Sci.*, **5**, 7, 1888.

[3] The writer hopes to have these results ready for informal presentation to the Astrophysical Conference to be held in connection with the dedication of the Yerkes Observatory, Oct. 18 to 22 (see p. 150 of this number).

length which is photographically or visually effective, which in the case of the refractor is or should be the wave-length of the light brought to minimum focus), we may put (11) in the form:

$$i^2 = \text{const } b^2 \beta^2, \tag{12}$$

where β is the angular aperture of the telescope objective. Hence we may say that for point sources the intensity at the center of the focal image varies directly as the product of the square of the linear aperture of the objective (or as its area), times the square of its angular aperture. The bearing of this result in photographic and visual work on the stars will be presently considered in connection with cases II and III.

II. *Intensity in the images of extended sources.*—The distribution in intensity in the image of a luminous source of finite size, whose elements vibrate independently, will be found by integration of the effects due to the individual points of which it is made up. Let x, y, be the coördinates of any point p in the source referred to any chosen point p_o, and ξ, η, the coördinates of a point in the focal plane referred to the geometrical image of p_o as origin. Then the effects of the element at x, y, at ξ, η, will be

$$dI^2_{II} = M \cdot 4\,(Br)^{-2} \cdot J_1^2\,(Br)\,dx\,dy.$$

Let $\phi(xy)$ denote intensity at the point x, y, in the source. Then the total effect at the point ξ, η, due to the whole source will be

$$I^2_{II} = 4\,M \iint^{\text{Area}} \phi\,(xy)\,\frac{J_1^2\,(Br)}{(Br)^2}\,dx \cdot dy, \tag{13}$$

where M and B have the values assigned in (3) and (6), and

$$r = \sqrt{\left(x\frac{f}{D} - \xi\right)^2 + \left(y\frac{f}{D} - \eta\right)^2}. \tag{14}$$

where D is the distance of the object from the image forming lens, and the quantities

$$x\frac{f}{D},\ y\frac{f}{D}$$

are, therefore, the focal plane coördinates of the geometrical image of p with reference to the origin $\xi = 0$, $\eta = 0$.

Instead of expressing the coördinates of a point in the focal plane in linear measure it is sometimes more convenient to

express them in angular measure. To do this we may put for small values of x, y, ξ, η:

$$\left.\begin{array}{ll}\xi = \gamma f, & \eta = \delta f, \\ x = \mu D, & y = \nu D.\end{array}\right\} \qquad \text{Put also } \frac{\pi b}{\lambda} = \kappa.$$

Then

$$\left.\begin{array}{l}\frac{r}{f} = \theta = \sqrt{(\mu-\gamma)^2 + (\nu-\delta)^2}, \\ dx\,dy = D^2\,d\mu\,d\nu,\end{array}\right\} \tag{15}$$

and (13) becomes

$$I_{II}^2 = MD^2 \int\int \phi(\mu\nu)\frac{4J_1^2(\kappa\theta)}{(\kappa\theta)^2}\,d\mu\,d\nu; \tag{16}$$

the integrations being extended over the whole of the source expressed in angular measure.

Still another expression which it is sometimes more convenient to use when the source is symmetrical is obtained directly from (1a) before integration. The effect at ξ, η, due to any element at x, y, is evidently[1]

$$\left.\begin{array}{l}I_{II}^2 = \int\int\int\int \cos\frac{2\pi}{\lambda f}\left(\xi - x\frac{f}{D}\right)x_1 \cos\frac{2\pi}{\lambda f}\left(\eta - y\frac{f}{D}\right)y_1\,dx_1\,dy_1\,dx\,dy \\ = D^2\int\int\int\int \cos\frac{2\kappa}{b}(\gamma-\mu)x_1 \cos\frac{2\kappa}{b}(\delta-\nu)y_1\,dx_1\,dy_1\,d\mu\,d\nu,\end{array}\right\} \tag{17}$$

the integration for $x_1 y_1$ being extended over the whole of the diffracting aperture as before, and that for x, y, or $(\mu, \nu,)$ over the whole of the source.

The integrations of the general expressions (13), (16), and (17) have only been accomplished for a few cases which, however, cover most of those met with in practice.

(1) *Luminous line of uniform intensity.*—In this case $\phi(xy) = 1$ and $x = dx$. Further, if the line is of any considerable length the intensity in the diffraction image at the point ξ will be the same for all values of η. Let us, therefore, consider the intensity along the line $\eta = 0$. We then get for r:

$$r^2 = \left(y\frac{f}{D}\right)^2 + \xi^2, \tag{18}$$

[1] MICHELSON "Visibility of Interference Fringes at the Focus of a Telescope," *Phil. Mag.*, 31, 256, March 1891.

and for I_{11}^2 from (13):

$$I_{11}^2 = \frac{1}{16}\frac{\pi^2 b^4}{\lambda^2 f^2}\,dx \int_{-\infty}^{+\infty} \frac{4J_1^2\left(\frac{\pi b}{\lambda f}\,r\right)}{\left(\frac{\pi b}{\lambda f}\,r\right)^2}\,dy. \qquad (19)$$

If the line is infinitely long and infinitely narrow this evidently becomes in the limit equal to

$$2\,d\xi \int_0^{\infty} I^2\,d\eta. \qquad (20)$$

In this form the integral has been investigated by Struve[1] and Rayleigh.[2] The latter finds for I_{11}^2 the value

$$I_{11}^2\,d\xi = \tfrac{1}{8}\,b^2 \,.\, \zeta^{-3} \,.\, d\zeta \,.\, K_1(2\zeta), \qquad (21)$$

where

$$\zeta = \frac{\pi b}{\lambda f}\,\xi,$$

and[3]

$$K_1(2\zeta) = \frac{2}{\pi}\left\{\frac{(2\zeta)^3}{1^2\cdot 3} - \frac{(2\zeta)^5}{1^2\cdot 3^2\cdot 5} + \frac{(2\zeta)^7}{1^2\cdot 3^2\cdot 5^2\cdot 7} - \ldots\ldots\right\} \qquad (22)$$

At the center ζ (or ξ) is zero, and we have (supposing λ constant as in (11)),

$$\left.\begin{aligned} i_{11} &= \frac{2}{3}\cdot\frac{b^3}{\lambda f} = \ldots\ldots \\ &= \text{const } b^2\,\beta \quad \ldots\ldots \end{aligned}\right\} \qquad (23)$$

or the intensity at the center of the image of a long fine line varies as the square of the linear aperture times the angular aperture.

(2) If the line is short (although still long compared with its width), $dy = \frac{D}{f}\,d\eta$, and the intensity of the image is decreased in the inverse ratio of the focal length, the lateral distribution in intensity remaining the same. For such lines we have, therefore,

$$\left.\begin{aligned} i_{11} &= \frac{2}{3}\,\frac{b^3}{\lambda f^2}\cdot D \ldots\ldots \\ &= \frac{2}{3}\,\frac{b^3}{\lambda f^2} \quad \ldots\ldots \end{aligned}\right\} \qquad (24)$$

[1] *Wied. Ann.*, 17, 1008, 1882.

[2] "Wave Theory," *Enc. Brit.*, 24, § 12.

[3] Rayleigh, "Theory of Sound," 2, 151, § 302.

when the apparent brightness of the line is, as supposed heretofore, unity per unit of angular length. If λ is regarded as constant we have

$$i_{11} = \text{const}\; b\,\beta^2, \tag{25}$$

or the intensity at the center of the image of a short line will vary as the linear aperture times the square of the angular aperture.

(3) *Source of finite magnitude.*—The expression for the intensity in this case (given by (13), (16), or (17)) is in general very complicated. If the source is symmetrical, say circular, we can, however, obtain an expression for the intensity on the center, o, of the geometrical image with comparative ease. This case is most simply dealt with by using polar coördinates. At the center $\xi = o$, $\eta = o$, and the influence of all points in the source at a distance

$$r' = \sqrt{x^2 + y^2} = \frac{D}{f}\,r$$

from the center will evidently be

$$2\pi r'\,dr' = 2\pi \left(\frac{D}{f}\right)^2 r\,dr.$$

The total effect due to the whole source of radius R will be

$$i'_{11} = \frac{8\pi D^2}{f^2} M \int_0^{\frac{f}{D}R} \phi(r) \frac{J_1^2(Br)}{(Br)^2}\, r\,dr. \tag{26}$$

Put $Br = z$. Then $dr = \dfrac{\lambda f}{\pi b}\, dz$, and we have

$$i'_{11} = \frac{1}{2}\cdot\frac{\pi b^2}{f^2} D^2 \int_0^{z_1} \phi\left(\frac{z}{B}\right) z^{-1}\cdot J_1^2(z)\cdot dz. \tag{26a}$$

When the intensity is uniform over the source $\phi\left(\dfrac{z}{B}\right) = 1$, and the integral assumes the known form

$$\int_0^{z_1} z^{-1}\cdot J_1^2(z)\,dz = \tfrac{1}{2}\left[J_1^2(z_1) + J_0^2(z_1)\right], \tag{27}$$

and the value of i_{11} is, therefore,

$$\left.\begin{aligned} i'_{11} &= \tfrac{1}{4}\pi D^2\cdot\frac{b^2}{f^2}\left[1 - J_1^2(z_1) - J_0^2(z_1)\right] \quad \ldots\ldots \\ &= \tfrac{1}{4}\pi\beta^2\left[1 - J_1^2\left(BR\frac{f}{D}\right) - J_0^2\left(BR\frac{f}{D}\right)\right] \ldots \end{aligned}\right\} \tag{28}$$

when the apparent brightness is unity per unit of angular surface as before.

When z_1 is small (equal, say, to dr) the value of $J_1^2(z_1) +$

$J_0^2(z_1)$ is simply $1 - \frac{z_1^2}{4}$. The total illumination at o is then

$$i'_{11} = M\pi(dr)^2, \tag{29}$$

as it evidently should be. When z_1 is large the sum of the squares of $J_1(z_1)$ and $J_0(z_1)$ tends toward zero, *i. e.*, the illumination at the center of the image of a large, uniformly illuminated area (which is the same as the illumination at any other point save near the edges of the image) becomes more and more nearly equal to

$$\tfrac{1}{4}\pi\frac{l^2}{f^2} = \tfrac{1}{4}\pi\beta^2, \tag{30}$$

as obtained on the principles of geometrical optics.

It is interesting to determine the size the object must attain before the influence of the term $J_1^2(z_1) + J_1^2(z_1)$ ceases to be felt. To show this I have calculated the following short table, which gives the value of this term for various values of z_1 expressed in terms of the resolving power of the telescope. To do this we put

$$\frac{f}{D}R = r_1 \text{ (the radius of the geometrical image),}$$

successively equal to $0.1\,af$, $0.2\,af$, $0.5\,af$, $1.0\,af$, $2\,af$. . . ., etc., where

$$af = m\frac{\lambda}{b}f$$

is the linear resolving power of the telescope objective of aperture b (for circular aperture $m = 1.1$).

TABLE I

Angular Diameter of Source	z_1	* $J_1^2(z)$	* $J_0^2(z)$	$J_1^2(z) + J_0^2(z)$
0.1a	0.3456	*0.0290	*0.9417	0.9707
0.2a	0.6911	0.1058	0.7816	0.8874
0.5a	1.728	0.3355	0.1458	0.4813
1.0a	3.456	0.0243	0.1396	0.1639
2.0a	6.911	0.0010	0.0891	0.0911
5.0a	17.28	0.0188	0.0186+	0.0374
10.0a	34.56	†0.0092+	†0.0092	0.0184
20.0a	69.11	†0.0046	†0.0046+	0.0092

The intensity at the center of the images of small spherical sources (such as planetary nebulæ, asteroids, small satellites,

* Interpolated from Dr. Meissel's "Tafel der Bessel'schen Functionen." *Abh. d. K. Akad. d. W.* Berlin, 1888.

† Calculated from the semi-convergent series for $J_1(z)$ and $J_0(z)$.

etc.), may therefore be less than ten per cent. as great as required by the geometrical law of intensity, which is practically fulfilled *only* for points whose angular distance from the edge of the geometrical image is from ten to twenty times the resolving power of the telescope.

III. *Intensity of illumination of the field due to an indefinitely extended luminous area.*— In this case there is not strictly speaking any image, or rather the image is one whose edge lies at infinity. The general expression for the illumination at any point ξ, η, in the field will be given by (13), (16), or (17), the integration being extended from $-\infty$ to $+\infty$ for both x and y. In the problem with which we are most directly concerned (the effect of the illumination of the sky)[1] the intensity is approximately uniform over the whole illuminated area. In this case $\phi(xy) = 1$, and we have for the illumination at any point in the field (which is in this case evidently the same as for the point at the center):

$$I_{\text{III}}^2 \quad \int_{-\infty}^{+\infty} dx \int_{-\infty}^{-\infty} I_1^2\, dy. \tag{31}$$

which [as in the case of a luminous line, II, (2), equation (19)] is identical with

$$\int_{-\infty}^{-\infty} d\xi \int_{-\infty}^{+\infty} I_1^2\, d\eta \quad \ldots . \tag{32}$$

This integral has been determined by Stokes,[2] who has shown that this integral is always equal to A, the area of the aperture, no matter what the form of the latter.

In this case $A = \frac{\pi b^2}{4}$, and the intensity at every point in the field of a telescope due to a uniform luminous area of infinite extent (more strictly an area extending over an entire hemisphere) is, therefore,

$$i_{\text{III}} = \text{const } b^2, \tag{33}$$

or the illumination of the field is proportional simply to the square of the linear aperture of the telescope, and is entirely independent of the focal length and angular aperture of the latter.

[1] See paper "The Effect of the General Illumination of the Sky on the Brightness of Field at the Focus of a Telescope." *M. N.*, **57**, 586, June 1897.

[2] *Trans. R. Soc. Edinburgh*, **20**, 317, 1853.

The expressions for i_{I}, i_{II}, i'_{II} and i_{III}, [(11), (23), (24), (28), (33)], as obtained above, enable us to express the contrast between image and field as functions of the aperture and focal length of the image forming lens, for most of the cases that arise in astrophotographic and astrospectrographic work. If i represents in general the intensity at the center of the image, and i_{III} that of the field, the contrast K will be represented by

$$K = \frac{i + i_{III}}{i_{III}} = 1 + \frac{i}{i_{III}}. \tag{34}$$

We have heretofore supposed that the intensity of the different sources considered has been such that their apparent brightness in each case has been unity. In actual practice, however, the apparent brightness will in general vary, and the intensity of the image will accordingly vary in the same proportion. If we let k be the factor expressing this variation the expression for the contrast becomes

$$K = 1 + \frac{k\, i}{k_{III}\, i_{III}}. \tag{35}$$

For the various cases which arise in practice we have:

(A) Contrast between point sources (stars and small asteroids, satellites, etc.), and general field due to III

$$K_{I} = 1 + \frac{k_a}{k_{III}} \frac{\pi b^2}{4\lambda^2 f^2} \qquad \text{from (11) and (13)}$$

$$= \text{const} \frac{k}{k_{III}} \beta^2. \tag{36}$$

(B) Contrast between line sources, and field,

(1) Long lines (meteor trails, lightning flashes, etc.)

$$K_{B} - 1 = \frac{k_b}{k_{III}} \cdot \frac{8}{3} \cdot \frac{b}{\pi\lambda f} \qquad \text{from (23) and (24)}$$

$$= \text{const} \frac{k_b}{k_{III}} \beta. \tag{37}$$

(2) Short lines (star trails, short meteor trails, bright line stellar spectra formed by an objective spectroscope and lengthened by motion parallel to slit, etc.),

$$K'_{B} - 1 = \frac{k_b}{k_{III}} \cdot \frac{8}{3} \cdot \frac{b}{\pi\lambda f^2} \qquad \text{from (24) and (33)}$$

$$= \text{const} \frac{k'_b}{k_{III}} \cdot \frac{1}{f} \cdot \beta. \tag{38}$$

(C) Contrast between finite sources of nearly uniform intensity over a considerable area, and field (nebulæ, comets, Moon, Sun, etc.),

$$K_C - 1 = \frac{k_c}{k_{III}} \cdot \frac{1}{f^2} \quad \text{from (28) and (33)} \qquad (39)$$

(D) Contrast between line sources and finite sources of uniform intensity (linear markings on lunar and planetary surfaces, etc.).

In such cases the lines are always short and we have from (24) and (28).

$$K_D - 1 = \frac{8}{3}\frac{k'_b}{k_c} \cdot \frac{b}{\pi\lambda} \cong \frac{k'_b}{k_c} \cdot \frac{1}{a}, \qquad (40)$$

a being the angular resolving power of the telescope.

The conclusions which follow from a consideration of the cases A and C (equations (36) and (39)), so far as the problems met with in astrophotographic work are concerned, have been presented in another paper.[1] Case B has been considered in its application to the problem of photographing meteor trails and meteoric spectra.[2] Case D has also been considered in connection with the problem of planetary observations, both visual[3] and photographic.[4] The consideration of cases A, B, and C in their applications to spectrographic and other astrophysical investigations will be taken up in the October number of this JOURNAL.

YERKES OBSERVATORY,
June 1897.

[1] "On the Conditions which Determine the Limiting Time of Exposure of Photographic Plates in Astronomical Photography," *A. N.*, Aug. 1897, and *Knowledge*, 20, 193, Aug. and Sept. 1897; see also note "The Effect of the General Illumination of the Sky on the Brightness of Field at the Focus of a Telescope," *M. N.*, 57, 193, June 1897.

[2] "On the Most Efficient Forms of Instrument for the Photographic Observation of Meteors and on Some New Methods of Determining their Parallax and Absolute Velocity."—To be soon published, probably in the *Astronomical Journal*.

[3] "On the Effect of the Size of an Objective on the Visibility of Linear Markings on the Planets."—To be published in the September number of the *Observatory*.

[4] "On the Photography of Planetary Surfaces; with Introductory Note on the Applications of Photography to Astronomical Research;" to be published in the October number of the *Observatory*. See also paper "On a Comparison of the Photographic and of the Hand and Eye Methods of Delineating the Form and Surface Markings of Celestial Objects," *Pop. Astron.*, 5, 200, August 1897.

Minor Contributions and Notes.

ALVAN GRAHAM CLARK.

It was with great regret that the scientific world learned of the death of Mr. Alvan G. Clark, which occurred at his residence in Cambridge, June 9, 1897. The immediate cause of his decease was apoplexy, although he had been in ill-health for some time previously. In anticipation of a more extended biography, the following sketch of his life has been prepared by one who stood near him, at the request of the family.

Mr. Clark was born in Fall River, Mass., July 10, 1832. His father, Alvan Clark, was born in Ashfield, Mass., March 8, 1804; he was a descendant of Thomas Clark, one of the early Pilgrim settlers. His mother was Maria (Pease) Clark. He had two sisters, Caroline and Maria Louise, and one brother, George Bassett, who was born in Lowell, February 14, 1827, and died in Cambridge, January 2, 1892.

While a student at Andover, George attempted the construction of a small reflecting telescope. In this way the attention of the father was first directed to optical pursuits, and about 1850 the firm of Alvan Clark & Sons was founded. The superiority of their lenses soon attracted the attention of astronomers, especially that of the Rev. W. R. Dawes, who introduced several of their larger productions abroad. Their instruments gradually increased in size, until in 1861 all former attainments were surpassed by the construction of one of 18¾ inches aperture for the Northwestern University, now located at Evanston, Ill. While testing this glass at Cambridge, Mr. Clark discovered the companion to Sirius, for which he was awarded the Lalande prize of the French Academy of Sciences. The Princeton University refractor, of 23 inches aperture, marked the next increase in size, after which two lenses of 26 inches diameter were made, one for the United States Naval Observatory at Washington, the other for the Leander McCormick Observatory of the University of Virginia. Then came the 30-inch refractor for the Imperial Observatory at Pulkowa, for which a gold medal was awarded by the Russian government. Finally, in

PLATE XVI

ALVAN G. CLARK AND CARL LUNDIN WITH THE CROWN LENS OF THE FORTY INCH OBJECTIVE.

YERKES OBSERVATORY, MAY 21, 1897.

1887, the famous Lick telescope was constructed, which ended the joint productions of the Clarks.

During the last five years Mr. Clark executed the 20-inch lens for the Denver Observatory; one of 24 inches aperture for Mr. Percival Lowell; the 24-inch photographic objective for the Harvard Observatory station at Arequipa, Peru; and finally, as a crowning triumph, the great Yerkes lens, 40 inches in diameter. This last he accompanied to its destination and superintended its final mounting only a few days before his death. In addition to his optical work, he was a member of several governmental eclipse expeditions, and, like his father, the discoverer of a number of close double stars.

In his domestic life he was exceedingly fortunate. He married, January 2, 1865, Mary Willard, daughter of Joseph A. Willard, who rendered him constant devotion throughout their married life. She died July 10, 1892. They had one son, Alvan, who died in youth, and three daughters.

In personal appearance and social intercourse Mr. Clark was unusually attractive. With finely cut features, of sympathetic nature, and serene temper, he drew to himself a host of friends. Fond of the companionship of intelligent men, interested in all that pertained to science, and delighting in travel and reminiscence, he had a storehouse of facts from which to draw. These he invested with a peculiar charm as he shared them not only with personal friends but the welcome visitor. An hour at his workshop was an unusual pleasure, both for the scientific man as well as the ordinary individual, and no one was ever turned away.

His sympathies were broad and deep, and his regard for his family and friends exceptionally strong. His love for the best literature was intense. Shakespeare and the poets were his especial favorites, and, endowed with a remarkably retentive memory, he could quote from them almost indefinitely.

To him death was the inevitable sequel of life, the gate to be opened by a kind and all wise Providence, and so without fear he met the future.

Thus has passed away the last of a trio of remarkable men, who had scaled the heighths of perfect achievement, and but a few days ago gave to the world its greatest masterpiece. O. C. WENDELL.

Mr. Clark's sudden death is especially felt by those who have been brought into close touch with him through his invaluable ser-

vices to the Yerkes Observatory. It was no small proof of devotion to his work and interest in its successful termination that he should be willing to leave his home after a nearly fatal stroke of apoplexy and to undertake a journey of over a thousand miles in order to accompany the forty-inch objective to its destination. We may well believe that he experienced no small degree of satisfaction in the safe arrival of the objective, its successful installation, its admirable performance, and its fortunate escape from injury in the subsequent accident to the rising-floor. The members of the staff of the Yerkes Observatory, fully recognizing the extent of their indebtedness to Alvan Graham Clark, unite with all friends of science in mourning his loss.

With characteristic hope of further progress, Mr. Clark was considering at the time of his death the possibility of constructing an objective still larger than his last great masterpiece. While he feared the effect of flexure, he felt that it might perhaps be possible to still further increase the aperture without endangering the performance of the objective.

It is a pleasure to add that the well-known firm name of Alvan Clark & Sons will still continue to be used. The men who shared with Mr. Clark the work of building great objectives and mountings will continue the business under the direction of Mr. Carl Lundin, who served the firm for twenty-five years. It gives the writer great pleasure to certify, after some acquaintance with his work, to Mr. Lundin's great ability as an optician.

George E. Hale.

EDWARD JAMES STONE.

The death of the Radcliffe Observer, so long and so favorably known for his work in England and at the Cape, comes as a serious loss to British astronomy. His star catalogues are indispensable to every astronomical library, and every observer has had reason to be grateful for his accurate places of both northern and southern stars.

Born in London in 1831, he went to Cambridge at a rather mature age, and carried off several honors. In 1860 he was appointed Chief Assistant at Greenwich, where he remained seven years, chiefly engaged with meridian observations, under the directorship of Airy. In addition to his observational work, he published various important memoirs, including determinations of the constants of nutation and refraction, investigations of the proper motion of stars, the motions of the solar

system in space, etc. He also received, in 1869, the Gold Medal of the Royal Astronomical Society, for his work at Greenwich in rediscussing the observations of the Transit of Venus in 1769.

Following his seven years with Airy came his mission to the Cape, where in a period of ten years he produced the well-known Cape Catalogue of 12,441 stars. Then came his appointment as Radcliffe Observer, a post which he held until his sudden death on May 9. Here he completed the Radcliffe Catalogue of 6424 stars, and conducted a variety of important investigations in other fields of work. In spite of his advanced years, he observed the last total eclipse in Nova Zembla, and was planning to visit India for the same purpose in 1898. Had he lived, it is certain that he would have made many more contributions to the literature of astronomy, as he retained to the last all his exceptional vigor of mind and body.

ARMINIO NOBILE.

We have received from the Royal Observatory of Naples an announcement of the death of Arminio Nobile, Second Astronomer of the Observatory, and Professor of Geodesy in the University of Naples. Professor Nobile was best known for his papers on geodetical subjects, which include many important contributions on determinations of latitude and longitude and related investigations. In addition to this he carried on much astronomical work, principally on double and multiple stars. He was a member of the Accademia dei Lincei and other important scientific societies, to whose publications he was a frequent contributor.

ADAM HILGER.

In these days of refined physical and astronomical measurements, and, as an eminent physicist has put it, of "discoveries in the sixth place of decimals," we are sometimes inclined, in our award of honors to those who have been directly concerned with some great advance in science by reason of some brilliant individual discovery or generalization, to forget, for the time being, the due proportion of praise due to those who have played a less conspicuous, though not less important, part in the history of science; but who, by the skillful and intelligent performance of the part allotted to them, whether it be, on the one hand the improvement of the refined instruments of research of mod-

ern observational science, or on the other the painful accumulation of accurate data by the faithful daily performance of routine and therefore at time irksome tasks; have been the ones who have in reality made these discoveries and generalizations possible. It is only when two such men as Hilger and the last of the famous firm of Alvan Clark & Sons are suddenly taken from us within a few weeks of each other, that we are brought to reflect upon, and realize fully, how large and important a part a few famous instrument makers and opticians of the latter part of this century have played in the development of modern observational astronomy, particularly that branch of it, the recent birth and growth of which have recently been so ably described by its founder, Sir William Huggins.[1] "By the death of Hilger . . . . the physical sciences, and especially astronomical physics, have suffered a loss which cannot immediately be made good. Standing in the front rank of practical opticians, he did much to promote scientific progress along various lines, and his thoroughly scientific training enabled him to undertake work of the highest character."[2]

Adam Hilger was born in Darmstadt in 1839, and for some years after attaining his majority he followed the profession of mechanical engineering in his native city. He then entered the famous establishment of Ertel in Munich. From there he went first to London, then to Paris, where he was engaged for some years with the firm of Lerebours & Secretan, and constructed many scientific instruments under the immediate direction of Foucault. Early in the seventies he returned to London, and after five years' work with Browning he set up the establishment of his own at Islington which has since become so famous. His work was held in the highest repute, both by scientific men and by his fellow artists. It is said that there is not a laboratory or observatory of importance in all England that does not possess one or more of his instruments and there are a great many in this country. A large part of the initial equipment of the Allegheny Astrophysical Observatory came from Mr. Hilger's workshops.

Of Mr. Hilger's personal characteristics there are many who can speak much better than the writer, who met him only once, in the fall of 1892, but who has always remembered that occasion with great

[1] "The New Astronomy: A Personal Retrospect," *Nineteenth Century*, June 1897.

[2] From a biographical notice by Mr. Fowler in the June number of the *Observatory*, to which the writer wishes to acknowledge his indebtedness for the few facts in regard to Mr. Hilger's life and scientific career which appear in this article.

pleasure. But his earnestness and enthusiasm in his work; his perfect readiness to show and explain the details of processes, which might by many other men in his position have been zealously guarded as trade secrets; his kindliness and simplicity of manner, and the entire absence of any element of self-consciousness or personal vanity when talking of his own work, combined to produce a personality that made a deep impression upon even those who knew him but slightly.

F. L. O. W.

ON THE ACTION OF COHERERS.

That a tube of filings changes its resistance when electric radiation falls on it is in itself an interesting fact. Questions arise. Do the filings *move* so as to make better contact? Does the process of electric welding take place as has been suggested by Lodge? Or is the medium changed by the radiation so that conduction of the current takes place? Experiments to throw light on these questions and also to determine the sensitiveness and constancy of various receivers and the influence of the dielectric were carried on during the autumn quarter of 1896 in the Ryerson Physical Laboratory.

(1) Tubes of glass containing iron filings, magnesium powder or graphite in air gave readings differing from each other by as much as 30 or 40 per cent. The mirror did not always return to zero upon tapping. The effect was ten times as strong when the radiation took place in oil as when it occurred in air. The response to long waves was feeble.

(2) Paraffin substituted for air made the receiver more sensitive but harder to regulate. Gelatine, on the other hand, allowed a current to flow and no change was observed after the radiation.

(3) A receiver with about one dozen steel spheres in a glass tube which they just fitted was very sensitive. Even when the end of a wire from the induction coil was brought within a distance of half a meter the mirror of the galvanometer (an ordinary D'Arsonval which, in this and the succeeding experiments, was short circuited by one-third ohm resistance) was thrown through twenty or thirty degrees. When the wheels of a Wimshurst machine three or four meters away, were turned through a small angle, though no sparking had yet taken place, a large deflection of the needle resulted. Bringing up a charged Leyden jar to the receiver did not affect it, but discharging the jar even by a moist

thread caused a large deflection. The effect therefore is due to sudden alteration in the strength of the field and is not similar to that of a secondary wire on a light suspended system — which is due to electrostatic action.

(4) A tube containing iron tacks 1^{cm} long in heavy paraffin oil or in lubricating oil was not nearly so sensitive as that of (3) but was far more constant. It was not affected by the turning of the Wimshurst machine until a spark passed between its knobs. This receiver, as well as that of (3), came accurately back to zero after tapping.

(5) Mercury, well shaken up in oil, formed into little globules varying from one to one-tenth millimeter in diameter. This, when placed in a glass tube, responded to the radiation, but was not very constant and was hard to tap back.[1]

(6) The receivers used have responded feebly to long, and very strongly to short, waves. An attempt was made to obtain a receiver having a definite period of vibration. Such a receiver would, if its vibrations were not too strongly damped, respond almost entirely to a definite radiation. For this purpose two small brass rods 6^{cm} long and about 4^{mm} diameter, were mounted end to end on hard rubber, one rod being fixed, the other capable of slow motion along its length. Though we used a delicate spring to produce this motion, the adjustment could not be made until a few drops of the oiled mercury of (5) were introduced between the adjacent ends. A small rubber tube over these ends served to keep the mercury in its place. Iron particles might have been used in place of the mercury. This receiver responded strongly to short waves and hardly at all to the long waves, but it was very inconstant compared with that of (4).

While writing this paper I noticed in *Nature*, June 17, 1897, an abstract of Mr. W. H. Preece's paper in which he described the receiver used by Mr. Marconi in signaling without wires. It is the same as the receiver just described. It did not appear as sensitive as the receiver of (3) or as that of (7).

(7) To make the adjustment more delicate two brass spheres two and one-half centimeters in diameter, were suspended by two fine cop-

[1] MR. ROLLO APPLEYARD, in the *Phil. Mag.*, May 1897, describes some interesting experiments on the action of strong electric fields on oiled mercury. He finds that the mercury globules run into one another. On the other hand, though I used the best microscopes obtainable here, no motion of the particle due to radiation could be observed.

per wires 15^{cm} long, to one of which was fastened a horizontal spiral spring. By a motion of the spring, the pressure between the spheres could be regulated. This proved to be the most sensitive receiver used, but it was affected by air currents and jars outside and inside the building.

(8) To remove the effect of air currents, to test the influence of heat and light on the receiver and its action in a vacuum the spheres were suspended in a jar which could be exhausted. No difference could be noticed between the action of the receiver in vacuum and in air except that in the former condition it was steadier. Throwing heat rays on the receiver did not decrease perceptibly its resistance, but, on the other hand, when the current had been set up by the electric radiation the heat rays always tended to bring the mirror back to zero.

(9) To see if any motion of the spheres occurred on account of the radiation, there was attached to one of the spheres a small mirror which was made one of the mirrors of an interferometer. Though great precautions were taken against air currents and vibrations, these effects could not be gotten rid of. The experiment, though unsatisfactory on this account, indicated that there was no motion of the spheres, and further, that if electric welding occurred it was of the most delicate nature.

(10) Finally, to test the influence of the dielectric, various oils, such as vaseline oil, mixtures of vaseline and lubricating oil, Venice turpentine, etc., were used in the receiver of (4). This general law was found — the more viscous the medium, the less lasting is the change of resistance and at the same time the less liable are the nails to be disturbed by the tapping back process. A medium which will allow the change of resistance to be permanent and yet sufficiently viscous not to allow the nails to be disturbed by the tapping back process, and such that after tapping the galvanometer returns to zero, is the one required for a quantitative receiver. A mixture of vaseline and lubricating oil was found to serve the purpose fairly well.

(11) *Conclusion.* The receiver is made more sensitive and at the same time less constant by decreasing the number and increasing the size of the conducting parts of the receiver.

The change of resistance may be accounted for thus. The electric spark between the conductors brushes aside the thin layer of non-conducting medium, and makes the intervening medium conducting. Whether this change will prove permanent or not depends on the

viscous and capillary forces of the surrounding medium. For air these forces are small so that the change should be permanent, as it usually is.

I am much indebted to Professors Michelson and Stratton for suggestions in connection with these experiments.

G. F. HULL.

RYERSON PHYSICAL LABORATORY,
THE UNIVERSITY OF CHICAGO,
June 1897.

ON THE MODE OF PRINTING MAPS OF SPECTRA AND TABLES OF WAVE-LENGTHS.

As a number of objections have been made to the mode of printing maps and tables adopted by the ASTROPHYSICAL JOURNAL, and as the question as to the most suitable mode has been reopened for discussion, it seems desirable that the arguments for and against the different systems should be stated, essentially as they were brought up for consideration at the first meeting of the Editorial Board, when the method now in use was adopted. In preparing the following statement I have consulted the minutes of the meeting referred to above.

1. *Mode of printing maps.*—If a map of the spectrum is printed with the red end toward the right, the letters assigned to the principal lines by Fraunhofer read in the reverse order. This seems to be a matter of very small importance. On the other hand, if the red end is placed on the left, the wave-lengths run in the reverse order. So far as convenience in reading the position of a line is concerned, this also seems to be a consideration of small importance, since a scale is read from right to left just about as easily as from left to right. A much greater weight attaches to the following consideration: it is frequently desirable to represent quantities of various kinds graphically, as functions of the wave-length, and observance of the usual convention of analytic geometry places the red end of the spectrum on the right. It was pointed out by Professor Rowland that concave grating spectroscopes are always constructed so that the wave-lengths increase towards the right, in accordance with the same convention.

The existence of unexplored regions at the ends of the spectrum does not affect the question of printing maps, as additions can be made equally well at either end.

The question of precedent was regarded as one of importance. In the following table is shown the usage of a number of prominent investigators, particularly of such as have published maps which are frequently consulted by spectroscopists. I have made a considerable number of additions to the names brought up at the meeting, and the list could be made much longer. With each authority is given the name of one map, or work in which a map is contained.

RED END TOWARD THE RIGHT.

Kirchhoff.—"Untersuchungen über das Sonnenspectrum."

Ångström.—"Recherches sur le spectre solaire."

Cornu.—"Sur le spectre normal du Soleil; partie ultra-violette."

Rutherfurd.—Photographic Map of the Diffraction Solar Spectrum.

Draper.—Photographic Map of the Diffraction Solar Spectrum.

Rowland.—Photographic Map of the Normal Solar Spectrum.

Higgs.—Photographic Atlas of the Normal Solar Spectrum.

Thalén.—"Mémoire sur la determination des longueurs d'onde des raies métalliques."

Huggins.—"On the Spectra of Some of the Chemical Elements."

Liveing and Dewar.—"On the Ultra-Violet Spectra of the Elements."

Vogel.—"Untersuchungen über das Sonnenspectrum."

Lockyer.—"Researches in Spectrum Analysis."

Abney.—"The Solar Spectrum from λ 7150 to λ 10000."

Langley.—"Researches on Solar Heat."

Pickering.—"The Draper Catalogue."

Young.—"The Sun."

RED END TOWARD THE LEFT.

Fraunhofer.—"Bestimmung des Brechungs- und Farbenzerstreuungs-Vermögens verschiedener Glasorten."

Lecoq de Boisbaudran.—"Spectres lumineux."

Fievez.—"Étude du spectre solaire."

Piazzi Smyth.—"Micrometical Measures of Gaseous Spectra."

Hartley and Adeney.—"Measurements of the Wave-lengths of Lines of High Refrangibility in the Spectra of Elementary Substances."

Thollon.—"Spectre solaire."

L. Becker.—"The Solar Spectrum at Medium and Low Altitudes."

Hasselberg.—"Untersuchungen über die Spectra der Metalle."

Kayser and Runge.—"Ueber die Spectren der Elemente."

Eder and Valenta.—Researches on the spectra of the elements.

The mode chosen (doubtless at random) by Fraunhofer was reversed by Angström, who has been followed by many other spectroscopists. It will be seen that while a good many maps which chiefly serve the purpose of illustration have the red end toward the left, most of the maps of the solar spectrum used as standards of reference (notably the maps of Angström and Rowland) have the red end toward the right.

The analogy with the keyboard of a piano, which has been urged as an argument in favor of placing the red end of the spectrum on the left, was not, I think, brought forward at the meeting of the Editorial Board. To me its importance seems to be merely that of a convenient mnemonic.

2. *Mode of printing tables.*—There seems to be no preponderance of authority in favor of either mode of printing wave-length tables. The Potsdam tables and the tables of Rowland begin with the short wave-lengths. The tables of Thalén, Kayser and Runge, and Hasselberg begin with the long wave-lengths, as do the tables in Watts' "Index of Spectra." Some authors have used both methods.

Tables of wave lengths will have to be added to at both ends as a result of future investigations. The infra-red region of the spectrum is the more extensive; on the other hand, the ultra-violet region contains the greater number of lines.

A strong argument for beginning tables with the long wave-lengths has arisen in the last few years through the discovery of extensive line series in the spectra of the elements. The natural numbers, substituted successively in the formulæ of Rydberg and Kayser and Runge, give a table of lines which begins with the long wave-lengths. It is possible, however, that future modifications of these formulæ may make it convenient to reverse this order. There are also series which run in the opposite direction from that above mentioned. The decision of the board that tables should begin with the short wave-lengths was therefore to a large extent arbitrary.

My personal opinion is that the practice of printing maps with the red end toward the right should not be changed, but that there is no objection to reversing the present mode of printing tables.

JAMES E. KEELER.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO. BULLETIN NO. 2.

COMPLETION OF THE YERKES TELESCOPE.

After many months of labor in erecting the mounting of the Yerkes telescope, Messrs. Warner & Swasey had early in May so far completed their work as to permit the 40-inch objective to be attached to the tube. The objective had been stored in the workshop of Messrs. Alvan Clark & Sons since October 1895, the date of its acceptance by Mr. Yerkes.[1] It therefore remained to transport it from Cambridgeport, Massachusetts, to Williams Bay, Wisconsin. Through the courtesy of the officials of the Wagner Palace Car Company and the Boston & Albany, New York Central, Lake Shore & Michigan Southern, and Chicago & Northwestern Railway Companies, a private car was furnished for the express purpose of carrying the objective, and free transportation was given over the respective roads. Mr. Marvin Hughitt, President of the Chicago & Northwestern Railway, to whom the Yerkes Observatory was already indebted for many signal favors, provided a special locomotive to bring the car containing the objective from Chicago to Williams Bay.

The flint and crown lenses were sewed up in soft cloth and packed in curled hair in separate boxes. They arrived safely at Williams Bay on May 19 in the charge of Mr. Alvan G. Clark and Mr. Lundin, who had come for the purpose of putting together the objective and attaching it to the telescope. This work was successfully completed on the following day, but on account of cloudy weather no observations could be made until the evening of May 21. On this and every other clear night up to May 29 the telescope was used with very satisfactory results. The seeing, which had been very fine during the warm days of early May, was not nearly so good in the exceptionally cold and unseasonable weather which prevailed during the latter part of the month. Nevertheless many objects were well seen, notably the Ring Nebula in Lyra, the great cluster in Hercules, and the Dumb-bell Nebula. The great light-gathering power of the telescope was well illustrated by the fact that Professor Barnard saw these and other objects better than he had ever seen them at Mt. Hamilton. An observation made by him, though of no special astronomical impor-

[1] For an account of the testing of the objective by Professor Keeler and the writer, see the Astrophysical Journal, 3, 154, February 1896.

tance, further testifies to the excellence of the 40-inch objective. Near Winnecke's companion to Vega, in a region which Professor Burnham had frequently examined with the Lick telescope, Professor Barnard saw and measured a faint star (Pos. 312°; Dist. 53″). Its distance from Vega is far too great to permit us to suppose that the two objects are physically connected; but the detection of a hitherto unseen star near so thoroughly observed an object as Vega affords some indication of the light-gathering power and perfection of polish of the 40-inch objective. Professor Burnham observed with the telescope on one night. Although the conditions were not favorable for a thorough test, his long experience enabled him to form a judgment regarding the optical performance of the instrument, with which he expressed himself as very much pleased. Taken together with the tests of the objective made by Professor Keeler and the writer in 1895, these favorable indications lead us to expect that the last great work of Alvan G. Clark will do honor to his memory.

In most respects the mounting of the large telescope proved to be very satisfactory. Even before there had been any opportunity to make the usual adjustments or to rate the driving-clock, a star brought to the center of the field of an eyepiece giving a power of 1000 would remain for a long time without apparent drift. With the telescope unclamped in right ascension a star under this power of course appeared to move very rapidly across the field of view. But as soon as the electric clamp was applied the star seemed to stop instantly, without vibration or drift, although the clock was called upon to set in motion a mass weighing some twenty tons. The steadiness of driving was admirable, the star images appearing almost motionless with reference to the micrometer wire.

The quick-motion motors were found to move the telescope well, and proved to be very useful for purposes of reversing and for rough settings. They could not be used to produce such small motions of the tube in both right ascension and declination as are required in picking up a star, on account of the long trains of gearing and shafting between the motors (in the clock room at the head of the column) and the moving parts. It was a matter of considerable difficulty to move the telescope by hand, but Messrs. Warner & Swasey, who had not completed their work when these observations were made, expect to be able to reduce the friction very decidedly at certain points, and to make the instrument as easily manageable as the Lick telescope.

The usual adjustments were being made when a most unfortunate accident deprived us of the use of the telescope.

ACCIDENT TO THE RISING-FLOOR.

On May 29, at 6:43 A. M., the south side of the rising floor fell to the ground from a height of 45 feet. The north side was forced against the vertical steel guides, and descended only a short distance. Several of the iron treads were stripped from the spiral stairway on the telescope column, but though it must have been badly jarred the instrument seems to have been otherwise uninjured. It is very fortunate that so little damage was done. No one was in the building when the accident occurred; Professor Barnard and Mr. Ellerman had been observing during the greater part of the night, but had gone home at dawn. Shortly before leaving they had raised the floor to within six inches of its highest level, where it was left for the convenience of Messrs. Warner & Swasey's men, who intended to continue in the morning their work of adjusting the mounting. An examination of the wreck at once revealed the cause of the accident. The wire cables which supported the floor had not been properly attached to it, and one or more of them had pulled out of the fastenings.

Messrs. Warner & Swasey, whose contract included the telescope mounting, dome, and rising-floor, undertook the work of reconstruction with little delay. New steel was shipped to the Observatory to take the place of the injured members, and in a few weeks the old floor had been taken down and another erected in its place. The work was pushed rapidly forward, and by the middle of August the rising-floor was once more ready for use. Great pains have been taken to make the new cable fastenings secure, and a repetition of the accident is certainly not to be feared.

APPROXIMATE POSITION OF THE YERKES OBSERVATORY.

The following provisional coördinates of the Yerkes Observatory have been determined by Mr. W. H. Wright, Fellow in Astronomy, with a 1¼-inch Bamberg universal instrument. The construction of the instrument does not permit of its use as a zenith telescope in the ordinary sense of the term. The vertical circle is read by micrometers, however, and with a slight modification of the usual procedure, Talcott's method has been employed. The longitude, which is not regarded as anything more than a rough approximation to the truth, has been

determined from comparisons of a sidereal chronometer with the daily time signal of the Western Union Telegraph Company at the Williams Bay station.

Approximate latitude of the Yerkes Observatory $= +42° \; 34' \; 15'' \pm$
Approximate longitude of the Yerkes Observatory $= 5^h \; 54^m \; 14^s \pm$ W.

DEDICATION OF THE YERKES OBSERVATORY.

The formal dedication of the Observatory will take place on October 21-22, 1897.[1] In connection with the dedication a series of informal conferences on astronomical and astrophysical subjects will be held at the Observatory on October 18, 19, 20, and 21. Although certain details remain to be arranged, the following provisional programme may perhaps be of interest at the present time:

Provisional Programme.

Oct. 18, Monday.

2 : 30 P.M. Fourth annual meeting of the Board of Editors of the ASTROPHYSICAL JOURNAL.

4 : 30 P.M. Opening session of informal conferences.
Informal talks on recent investigations, including:
- Professor Wadsworth on the Application of Diffraction Phenomena to Astronomical and Astrophysical Measurements.
- Dr. Hull on Electric Radiation.

(Other titles may be added.)

7 : 30 P.M. Professor Wadsworth will demonstrate with the 40-inch Yerkes telescope the application of interference methods to astronomical measurements.

Oct. 19, Tuesday.

9 : 00 A.M. Second session of conferences.
- Professor Crew on the Source of the Characteristic Spectrum of the Metallic Arc.
- Professor Hale on a Remarkable Change in the Reversing Layer near a Sun-spot.
- Dr. Humphreys on the Effect of Pressure on Wave-length.
- Professor Keeler on the Spectra of Stars of Secchi's Third Type.
- Professor Lord on Researches in Stellar Spectrography, (the spectrograph of the Emerson McMillin Observatory will be exhibited).
- Professor Runge on Oxygen in the Sun.

[1] Necessarily postponed from October 1.

Oct. 19, Tuesday—*continued.*

Dr. Wilczynski on Hydrodynamical Investigations of the Solar Rotation.

Professor Stone on the Great Nebula of Orion.

(Other titles may be added.)

2 : 15 P.M. Address on the Yerkes Observatory by Professor George E. Hale, Director.

3 : 00 P.M. Professor Hale will show various solar phenomena with the 40-inch Yerkes telescope, including the chromosphere and prominences. the reversal of the H and K lines in prominences and faculæ, the duplication of the D_3 line, etc.

Mr. Ellerman will exhibit the solar spectrum, including the infra-red and the ultra-violet regions (heliostat room.)

Experimental demonstrations will be given in the Observatory laboratories as follows :

The effect of pressure on wave-length (Dr. Humphreys).

Measurements of wave-lengths in the infra-red spectrum (Professor Wadsworth).

Analysis of electric radiation by means of the interferometer (Dr. Hull).

Experiments with the rotating arc and the "hooded" arc (Professor Crew).

Demonstrations in the Optical Shop :

Process of grinding a 5-foot speculum (Mr. Ritchey).

Exhibition of Foucault's method of testing the figure of mirrors (Mr. Ritchey).

Exhibition of plane parallel plates and other optical surfaces. Demonstrations of methods of testing. (Dr. Brashear).

Demonstrations in the Instrument Shop :

The instrument shop will be in operation, and a 24-inch heliostat will be shown in process of construction (Mr. Lorenz).

Wadsworth's method of making a perfect straight-edge (Mr. Mors).

Rowland's method of grinding a perfect screw (Mr. Mors).

7 : 30 P.M. Professor Barnard will show the following objects with the 40-inch Yerkes telescope :

N. G. C. 224 (Andromeda Nebula).

N. G. C. 598.

N. G. C. 1976 (Orion Nebula).

N. G. C. 2245 (cometary nebula).

N. G. C. 2392 (planetary nebula).

Oct. 19, Tuesday—*continued.*

N. G. C. 6543 (planetary nebula).

N. G. C. 6618 (Swan nebula).

N. G. C. 6720 (annular nebula).

N. G. C. 7009 ("Saturn" nebula).

N. G. C. 7078 (globular cluster).

R. Leporis (Hind's crimson star).

Selected variable stars.

The 12-inch refractor and Mr. Ritchey's 24-inch reflector will be used for miscellaneous observations.

Oct. 20, Wednesday.

10 : 30 A.M. Third session of conferences.

Professor Comstock on Determinations of Stellar Parallax and on Investigations of the Lunar Atmosphere.

Professor Doolittle on the Latitude Work of the Flower Observatory.

Professor Rees on the Variation of Latitude and the Reduction of the Rutherford Photographs.

Professor Myers on the System of β Lyrae.

Professor Pritchett on Personal Equation in Longitude Determination.

(Other titles may be added).

2 : 30 P.M. Fourth session of conferences.

Professor Barnard on Astronomical Photography (illustrated with lantern views).

Professor Hough on Jovian Phenomena.

Professor Pickering on the Work of the Harvard College Observatory.

Father Hagen on an Atlas of Variable Stars.

Professor Poor on a New Form of Mirror for Reflecting Telescopes.

Father Hedrick on the Photochronograph (the instrument used at the Georgetown College Observatory will be shown).

7 : 30 P.M. Professor Hale will show the spectra of the following objects with the 40-inch Yerkes telescope:

N. G. C. 1976 (Orion nebula).

N. G. C. 7027.

α Tauri.

α Orionis.

α Cygni.

α Ursae Majoris.

α Cassiopeiae.

α Canis Majoris.

Oct. 21, Thursday.

9:30 A.M. Final session of conferences.

Dr. Laves on the Teaching of Theoretical Astronomy in America and on Jacobi's Investigations in Theoretical Astronomy.

(Other titles may be added.)

11:00 A.M. Arrival at the Observatory of the Trustees, members of the Faculty, students, and guests of the University of Chicago.

11:30 A.M. Formal presentation and acceptance of the Yerkes Observatory.

1:00 P.M. Luncheon served to official guests, Trustees and members of the Faculty.

2:00 P.M. to 3:30 P.M. Inspection of the Observatory.

4:00 P.M. Departure for Chicago of the special train provided for the Trustees and official guests.

8:30 P.M. Reception to Mr. and Mrs. Yerkes, the visiting men of science, and members of the Observatory staff.

Oct. 22, Friday.

10:00 A.M. Inspection of the Ryerson Physical Laboratory and other buildings of the University of Chicago.

In the Ryerson Laboratory Professors Michelson and Stratton will demonstrate the effect of a magnetic field on radiation, and exhibit an interferential comparer and a new form of harmonic analyzer.

1:00 P.M. Luncheon given by the President of the University to the visiting men of science and other official guests.

3:00 P.M. Address by Professor Simon Newcomb, LL.D.

7:00 P.M. Banquet to the visiting men of science.

GEORGE E. HALE.

YERKES OBSERVATORY,
July 1897.

A NOTE ON THE EFFECT OF HEAT ON PHOSPHORESCENCE.

IN connection with note on the above subject in *Nature*[1] of June 3d attention should be called to the recent and important work in the same field of Professors Wiedemann and Schmidt, who within the

[1] "Effect of a Change of Temperature on Phosphorescent Substances," Mr. Ralph Cusack, *Nature*, **56**, 102, June 3, 1897.

last two years have published in *Wiedemann's Annalen* and elsewhere[1] several very interesting papers dealing with the luminescent properties of various substances in both the solid and the fluid state. This work will be reviewed more at length in a subsequent number of this JOURNAL. In the present note I will only refer to certain experiments on the effect of a change in temperature on the phosphorescent properties of solids, which are described in their paper "Über Luminescenz von festen Körper und festen Lösungen," published about a year and a half ago.[2] The results of these experiments are summed up in the following conclusions:

7. Ein vorheriges Erhitzen wirkt auf die luminescirenden Substanzen in doppelter Weise: *a*) durch das Erhitzen werden die Substanzen (z. B. Strontiumsulfat) im allgemeinen dichter, bez. in andere Modificationen übergeführt oder, *b*) chemisch verändert.

   In beiden Fällen kann die Farbe des Leuchtens durch das Erhitzen wesentlich verändert werden.

8. Je stärker ein Körper bei seiner Darstellung erhitzt worden ist, desto länger leuchtet er nach. Diese Regel gilt ausnahmslos.

10. Für den Einfluss der Temperatur des luminescirenden Körpers auf das Leuchten ergiebt sich:
    a) die durch die starken Kathodenstrahlen hervorgerufene Luminescenz bleibt von -80° bis zu den höchsten erreichten Temperaturen ca. 500° erhalten;
    b) bei niederen Temperaturen ist die Intensität der Luminescenz[3] grösser als bei höheren;
    c) das Nachleuchten verschwindet bei höheren Temperaturen; es ist bei -80° länger als bei 0°;
    d) die Farbe ändert sich manchmal so, dass zu den bei den niederen Temperaturen vorhandenen Strahlen bei höheren Temperaturen brechbarere hinzutreten, vgl. $M_gSO_4 + 1\ \%$ M_nSO_4, $Q_nSO_4 + 1\ \%$ M_nSO_4. (Versuche bei niederen Temperaturen.)

Der Einfluss der Temperatur auf die Wellenlängen der Chemieluminescenz wäre also ähnlich demjenigen auf die Wellenlängen eines

[1] See this JOURNAL, 3, 207, March 1897.

[2] *Wied. Ann.*, 56, 112, October 1895.

[3] Bei Erregung mit den schwächeren Sonnenstrahlen liegen die Verhältnisse etwas anders.

in gewöhnlicher Weise glühenden Körpers; auch bei letzterem verschiebt sich das Maximum der Emission mit steigender Temperatur nach dem Violet.

The effect of intense *preliminary* heating in increasing the phosphorescent power of barium sulphide was independently observed by the writer while engaged in experiments on the preparation of phosphorographic plates for solar work in September and October 1895, just before the paper of Professors Wiedemann and Schmidt appeared. A note in reference to this observation was published in this JOURNAL for November 1896.[1] At that time, owing to temporary lack of library facilities, I had not seen the paper in *Wiedemann's Annalen*, or I should certainly have referred to it. I take this opportunity of doing so and of according to the authors full priority both of observation and of publication.

F. L. O. WADSWORTH.

YERKES OBSERVATORY,
July 22, 1897.

ON THE REVERSING STRATUM AND ITS SPECTRUM, AND ON THE SPECTRUM OF THE CORONA.[2]

THE observation made by the writer in 1870, described on pages 82 and 83 of the last edition of *The Sun*, received a beautiful photographic confirmation during the total eclipse of 1896. Mr. Shackleton, the photographer of an English party at a station in Nova Zembla (the only party which was not baffled by bad weather), secured an instantaneous photograph at the critical moment with a so-called "prismatic camera," which is simply a camera with (in this case) two large prisms in front of its lens, no collimator being used — a photographic "slitless spectroscope."

When the Sun's disk is reduced to an extremely narrow crescent by the encroaching Moon, this crescent itself acts like the slit of an ordinary spectroscope, and photographs taken with such an instrument immediately before totality are just like the usual solar spectrum, except

[1] "Note on the Preparation of Phosphorescent Barium Sulphide," *Ap. J.*, 4, 308, November 1896.

[2] The above note will appear as an addendum in a forthcoming edition of Professor Young's well-known work, *The Sun*. The editor of the ASTROPHYSICAL JOURNAL has in his possession copies of Mr. Shackleton's remarkable photographs, which will be reproduced as soon as Sir Norman Lockyer desires to have them published.

that the dark Fraunhofer lines are replaced by dark crescents—*negative* images, so to speak, of the still uncovered portion of the disk. As soon, however, as the photosphere disappears, the remaining, much fainter crescent is simply the solar atmosphere, and if the observation of 1870 is correct, its photograph ought to show a series of *bright* images replacing the former dark ones, and it did.

Mr. Shackleton watched the waning crescent with a small direct-vision prism held in the hand, and at the instant when the brilliant dark-line spectrum vanished he "pressed the button" and caught on his plate the "flash-spectrum," as it has been called by Mr. Lockyer. The exposure was about half a second. The photograph shows a long range of several hundred bright, curved images, of which there are nearly 250 in the blue portion of the spectrum between F and H. About twenty-five are much more extensive and conspicuous than the others, and are images of the chromosphere and prominences. They are due to hydrogen, calcium, helium, strontium, and one or two other elements which often appear in the chromosphere. The rest are simply reversals of the Fraunhofer lines, as Mr. Shackleton has shown by developing the flash-spectrum into a bright-line spectrum of the usual form (which is easily done by a simple mechanical contrivance), and comparing it with an ordinary dark-line solar spectrum photographed with the same camera and prisms, but with the addition of a collimator and slit. The agreement is practically complete, although there are two or three somewhat conspicuous Fraunhofer lines which are missing in the flash-spectrum, probably because they originate not above the surface of the photosphere, but in its depths, as probably also do the wide hazy shadings that accompany the H and K lines and some others, but this is a matter for further investigation.

A second photograph, taken not more than five or six seconds later, shows only the chromospheric images, proving of course that the stratum of the solar atmosphere which produces the Fraunhofer lines by its absorption must be extremely thin. This is perfectly in accordance with the view expressed on pages 325 and 339, and does not at all favor the opposite "Dissociation Theory" of Mr. Lockyer, according to which the lines, many of them at least, are produced only at a considerable elevation, where the temperature is low enough to allow the recombination of elements dissociated in the hotter regions underneath.

A photograph made by the same instrument about the middle of

the eclipse, with an exposure of nearly a minute, shows very finely the green coronal ring, corresponding to the old "1474 line," and several others in addition. These are all in the violet part of the spectrum, and are extremely faint, excepting one which is a little below H. They are all probably due to the same hypothetical element, still unidentified, but provisionally named "coronium." The photograph also seems to make it certain that *hydrogen*, *helium*, and *calcium*, though brilliantly conspicuous upon the plate in the images of the prominences, *are entirely absent from the corona*, a result agreeing with that deduced from similar photographs made in 1893, but only recently published. It is quite clear that the earlier observations (referred to on pages 260, 261, and 262) were misleading from the fact that the apparatus did not sufficiently guard against the effects of illumination of the air by light from the prominences. C. A. YOUNG.

NOTE ON THE PRESENCE OF VANADIUM IN RUTILE.

IN connection with Professor Hasselberg's "Note on the Chemical Composition of the Mineral Rutile" in the last number of this JOURNAL, Professor Rowland wishes to have it stated that he discovered all the important vanadium lines in the spectrum of rutile some four or five years ago. He also found traces of vanadium in specimens of titanic acid, and noticed that the strongest of the vanadium lines were given in Kayser and Runge's tables as iron lines.

NOTE ON THE RELATIVE FREQUENCY OF THE H AND K LINES IN THE SPECTRUM OF THE CHROMOSPHERE.

IN Sir William and Lady Huggins' interesting and important article (p. 77) reference is made to the fact that H and K are recorded with relative frequencies of 75 and 50, respectively, in Young's *Catalogue of the Chromosphere Lines*. It has seemed to me desirable to point out that in all probability a relative frequency of 100 would have been ascribed to both lines had photographic rather than visual methods been employed in Professor Young's very important work at Mt. Sherman. During my four years of solar work at the Kenwood Observatory I do not remember that I ever photographed the ultra-violet spectrum of

the chromosphere and prominences without recording both of these lines. Moreover, K is almost invariably stronger than H in such spectra. The only way in which I can account for the values of the relative frequency given by Professor Young is by supposing that his eye is decidedly more sensitive to H light than to the more refrangible light of the K line. I think Professor Young will agree with me as to the contradictory evidence afforded by the photographic method.

I mention this point, not because it has any bearing upon Sir William Huggins' valuable conclusions, but rather because it would seem that in this critical region of the spectrum, photographic results are to be preferred to those obtained visually.[1]

GEORGE E. HALE.

NOTICE REGARDING REPRINTS.

THE attention of contributors to the ASTROPHYSICAL JOURNAL is called to the fact that hereafter *one hundred* reprints, bound in covers, of each article accepted for publication will be furnished to the author free of charge, provided a request to this effect is sent with the manuscript.

[1] Since the above note was written I have received the following letter from Professor Young, which goes to confirm the opinion expressed regarding the relative frequency of the H and K lines: "The numbers given in my catalogue of chromosphere lines were intended to represent the relative frequency with which I was able *to observe them* in 1872: and K is a good deal more difficult to observe *visually* than H, from being nearer to the limit of ordinary visual observation in the spectrum. Later, by the help of the fluorescent eyepiece I carried the limit up above 3875, and was able to observe H at 3880. Even before your photographic operations I had become satisfied that both H and K were *always* present in the chromosphere spectrum, though I was not able to observe them both. I have not my books with me, and cannot now give references, but am very sure that I had printed that opinion more than ten years ago, probably in one of my 'spectroscopic notes' in the *American Journal of Science*. I think it quite likely, as you suggest, that my eye falls off more rapidly in sensitiveness towards the violet end of the spectrum than is the case with many. I know that Dr. Brackett can always see further above K than I can: in fact, with me it is usually pretty hard to see K at all except with the interposition of a purple glass to cut off the rest of the light."

Reviews.

Die Gravitations Constante, die Masse und mittlere Dichte der Erde, von Dr. Carl Braun, S. J. Abhandlung der Mathematisch Naturwissenschaftlichen Classe der Kaiserlichen Akademie der Wissenschaften, Wien, Band 44, pp. 74+iii.

A little over a year ago (April 1896) the writer reviewed in this Journal the important work of Professor Boys on the determination of the Newtonian constant, which was then considered to have given us a value "fully ten times better than any preceding determination . . . . and . . . . for the first time comparable (in accuracy) with the results attained in our other physical measurements." The work of Dr. Braun in this same field, which is fully described in the above memoir, is perhaps less elegant and finished than that of Professor Boys as regards some of the details of the design, construction, and manipulation of the apparatus, but, in view of the great length of time devoted to it, the variety of methods of observation employed, the careful consideration of all sources of error, and the painstaking means adopted to eliminate them as far as possible from the measurements; it must, I think, be admitted as worthy of ranking with the work of the latter in point of accuracy, which is perhaps the highest praise that can be bestowed upon it. At the same time it must be remarked that in the opinion of the reviewer Boys' apparatus, modified so as to allow the suspended system to swing in a vacuum, and in some other minor particulars (see review already referred to), is capable of giving, under favorable circumstances, a much higher degree of accuracy than has been attained or can be attained with any other form as yet described or suggested. Had conditions of observation been favorable, Professor Boys would no doubt have succeeded in attaining the degree of accuracy which he himself has considered possible with it, *i. e.*, one part in ten thousand.

Dr. Braun's memoir is divided into six parts, with a supplement. Part I, the introduction, deals with the relation between the gravitation constant G, the mass of the earth M, and the mean density of the Earth D. Part II contains a full description of the apparatus and of the methods of measurement employed to determine its constants.

The apparatus used was that of Cavendish, considerably reduced in size, but still much larger than that employed by Boys. The attracted (swinging) system consisted of two gilded brass balls hung at the ends of a light balance-arm shaped frame of copper wire, which carried at the center a mirror about $3.^{cm}3$ in diameter, and which was suspended from a heavy tripod by a brass wire 104^{cm} long and $0.^{cm}0055$ in diameter. The upper end of the wire was attached to a torsion head, connected by clockwork with a shaft carrying a small magnet, which could be revolved by means of another magnet held outside the case, and the torsion head thus turned round without touching any part of the apparatus. This was a very necessary provision, as it was found that the creep of the index mark, due to the gradual change in the suspending wire, amounted during the course of the experiments, 1890–1895, to more than nine times the length of the scale. The whole suspended system was placed under a tall glass receiver connected with an air pump, by means of which it could be exhausted down to a pressure of about 2 to 5^{mm} of mercury. To determine the position of the suspended system a mirror inclined at 45° to the horizontal was placed in front of the mirror on the torsion rod, so as to reflect the light from the latter down through the base plate on to the horizontal objective of the observing telescope, of 46^{cm} focal length, placed just beneath. For convenience of observation a 45° prism was placed in the tube of the telescope, just behind the objective, so that the eyepiece of the latter was horizontal. Deflections were read by means of a fine glass scale $S_{\prime\prime}$, fixed in the focal plane of the eyepiece; the index mark being a line on a second brightly illuminated glass plate $S_{\prime}$, set in the lower side of the telescope tube, the light from which is thrown down the axis of the latter and on to the mirror on the torsion arm by a slip of optical glass placed just in front of $S_{\prime\prime}$. The distance of the scales from the mirror was so adjusted that a movement through one scale division corresponded to a movement of the torsion arm through an angle of 0.001 radian, *i. e.*, $3'.47$; as determined both by calculation and by observation with a theodolite. In order to observe a larger angular deflection than corresponded to simply one length of the scale, three index marks were placed on $S_{\prime}$ at a carefully determined distance apart. By observing the marks at opposite ends successively, a movement of the torsion arm corresponding to nearly ninety scale divisions, or about 5°, could be observed. The suspended system was set swinging by means of a light magnetized steel fork, the arms of which could

be brought against the beam on either side by means of an external magnet.

The moment of inertia of the torsion arm was determined both by calculation and by experiment in the usual manner, with very satisfactory agreement. The attracting system consisted of two spheres suspended outside the receiver from a graduated metal ring mounted so as to revolve concentrically with the axis of the torsion wire. Two sets of attracting masses were used, one set a pair of solid brass spheres, the other a pair of hollow iron spheres filled with mercury. The distance between the center of these masses was measured by means of an optical compass quite similar to that used by Professor Boys for a similar purpose, and the vertical positions were determined by means of a cathetometer. The principal dimensions of the apparatus were as follows:

Weights of small attracted masses (brass spheres).

$$M_1 = 54^{gm}.554$$
$$M_2 = 53\ .977$$
$$\text{mean} = 54\ .266$$

Distance between centers of small masses.

$$\text{right arm} = 12^{cm}.370$$
$$\text{left arm} = 12\ .243$$
$$24\ .613 \text{ at } 17°\ C.$$

Weights of large attracting masses (iron globes filled with mercury).

$$9184^{gm}.75$$
$$9107\ .57$$
$$\text{mean}\quad 9146\ .16$$

Distance between centers of large masses,

$$\text{right arm} = 20^{cm}.938$$
$$\text{left arm} = 20\ .800$$
$$41\ .738$$

The whole apparatus was mounted on a heavy stone slab in the corner of a room set apart for the work. It was protected from temperature changes, electrical effects, etc., by successive screens of tin and cloth.

Part III deals with the method of observation. Two independent methods were used, the first the original deflection method used by Cavendish (the same as used by Boys); the second the oscillation method first used by Reich. In the first method, which is too well known to need description, Dr. Braun determined the zero points, not by observations of successive elongations, as has usually been done, but by observing on a chronograph the times of transit in both directions of several divisions near the center of swing, and then determining from the successive differences the point about which the time of oscillation was the same in both directions. This was considered somewhat more accurate than the method of elongations. In the second method the attracting weights are placed in line with the centers of the attracted masses, in which position they act to increase the restoring force, and thus diminish the time of swing as compared with that observed when the masses are removed or turned at right angles to the first position. In the case of Dr. Braun's apparatus the time of vibration was changed from about 1251 seconds (for masses in line) to about 1296.6 seconds (for masses at right angles).

Part IV deals with the various corrections which have to be applied to the various observations, particularly those of the deflection and time of oscillation of the suspended system, for the various effects of elastic fatigue (*nachwirkung*), and "creep" of the torsion wire, damping of the residual air, changes in temperature, eccentricity of the suspended and attracting systems, etc. It would take too much space in this review to consider these various corrections in detail; suffice it to say that all possible sources of error seem to have been carefully considered and corrected for.

Part V gives in detail the various observations for the years 1892 and 1894, which were those finally chosen as the ones upon which to base the final determination of G and D. The observations of the previous years, 1887–1892, were rejected mainly on account of the fact that they had been made before the air pressure in the receiver had been sufficiently reduced to avoid irregularities of swing, etc. The observations in 1892 were made with a mean pressure of about 16^{mm}, and those of 1894 with a mean pressure of about 4^{mm} in the receiver.

The mean results for D by the deflection method for 1892 and 1894 were:

For 189[illegible], D = [illegible] 005, based on eleven complete observations.

For 1894, $D = 5.529 \pm .0016$, based on nine complete observations.

The mean results by the oscillation method were:

For 1892, $D = 5.523 \pm .0026$, based on fifteen complete observations.

For 1894, $D = 5.534 \pm .0032$, based on eleven complete observations.

Part VI and the supplement deal with the final discussion and correction of all the results obtained by both methods for the years 1892 and 1894. The most probable values of D as finally determined were:

By the deflection method, 1892, 5.529; 1894, 5.526.

By the oscillation method, 1892, 5.532; 1894, 5.531.

And for the mean result, $D = 5.527 \pm .001$.

Which gives for G

$$G = 6.6579 \times 10^{-8}.$$

This result is practically the same as that obtained by Professor Boys, *i. e.*, $G = 6.6576$. It will perhaps be remembered that in the review of Boys' work the writer pointed out that it seemed to him, from a consideration of the individual determinations upon which this latter value was based, that it was somewhat too low. Whether this be so or not, it is well not to be too much influenced by the striking agreement between these two determinations. Each is admitted to be uncertain by at least one and perhaps two units in the fourth place, so that the agreement to even the fifth figure is more likely to be a striking coincidence than an indication of real accuracy attained. Results obtained by other methods, notably the one obtained by Poynting, (1880–1891) by the balance method, have differed quite widely from the above, and while they are undoubtedly less accurate than the latter, so far as accidental errors of observation are concerned, it may be that the Cavendish method is subject to some constant source of error as yet unsuspected and undiscovered.

F. L. O. W.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

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NOTICE

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

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PLATE XVII.

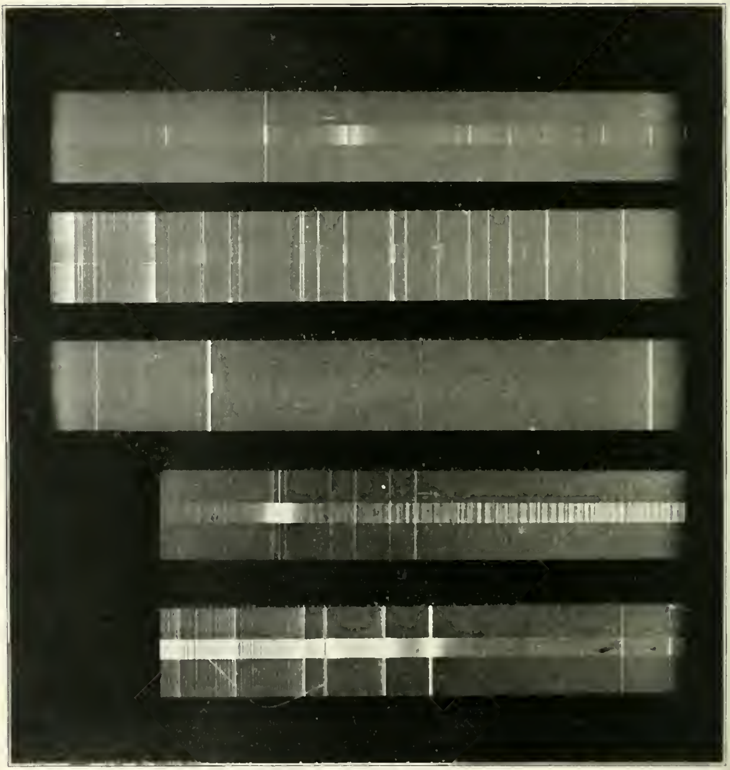
I.

II.

III.

IV.

V.



SHIFTS OF SPECTRAL LINES DUE TO PRESSURE

I. A pair of sodium lines which widen toward the violet, but shift toward the red.
II. New Concord Meteorite. All the iron lines are not equally shifted. Cyanogen bands unaffected.
III. Two classes of copper lines having different shifts.
IV. Large shifts of two potassium lines.
V. Shifts of the rubidium lines in the cyanogen band.

THE

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CHANGES IN THE WAVE-FREQUENCIES OF THE LINES OF EMISSION SPECTRA OF ELEMENTS, THEIR DEPENDENCE UPON THE ELEMENTS THEMSELVES AND UPON THE PHYSICAL CONDITIONS UNDER WHICH THEY ARE PRODUCED.

By W. J. Humphreys.

PRELIMINARY REMARKS.

It is well known to spectroscopists that the character of the emission spectrum of an element depends greatly upon the physical conditions under which it is produced. If the element is in the solid or liquid state its spectrum is continuous, but discontinuous when it is in the form of an attenuated gas. The discontinuous spectrum may consist either of bands or of isolated lines or of both, according in part to the substance used, and in part to the conditions under which its spectrum is formed. In general the number of lines that can be detected and their intensities increase with increase of temperature, though their relative intensities may change very greatly as the temperature is raised. Increase in the density of a gas or vapor increases the width of its spectral lines; some of them spread out symmetrically, others unsymmetrically. In the latter case the chief increase in width is usually, but not always, towards the less refrangible or red

end of the spectrum. A somewhat similar increase in the width of lines (both emission and absorption), together with certain polarization phenomena, may be produced, according to Zeeman,[1] by placing the vapor to which the lines are due in a strong magnetic field.

Again, whether a line is reversed or not depends in part at least upon the thickness and density of the absorbing layer. Finally a single element, as argon for instance, may give one or another of two distinct line spectra owing to the character of the electric discharge used to produce it, and to the pressure of the gas.

Not only emission but absorption spectra also are known to be subject to changes. One of the most important of these changes was observed by Kundt who, in describing it, says that the position of an absorption band depends upon the substance in which it is dissolved or incorporated, that the band is displaced towards the red end of the spectrum when the substance producing it is dissolved in a strongly dispersive medium; or, to use his own words, as they occur in an article on absorption spectra.[2] "Hat ein farbloses Lösungsmittel ein beträchtlich grösseres Brechungs-und Dispersionsvermögen als ein anderes, so liegen die Absorptionsstreifen einer in den Medien gelösten Substanz bei Anwendung des ersten Mittels dem roten Ende des Spectrums näher als bei Benutzung des zweiten."

In view of the reciprocal relation between absorption and emission of radiations, it would seem that one might suspect the possibility of a similar phenomenon, that is shift of lines, in the case of emission spectra. Indeed some observers have reported shifts of certain spectral lines, and besides something of the kind is suggested by the theories of both Lommel[3] and Wüllner.[4]

[1] "On the influence of Magnetization on the Nature of the Light Emitted by a Substance."—*Phil. Mag.*, March 1897; this JOURNAL, 5, 332, 1897.

[2] "Ueber den Einfluss des Lösungsmittels auf die Absorptionsspectra geloster absorbirender Medien."—*Wied. Ann.*, 4, 34.

[3] "Theorie der Absorption und Fluorescenz."—*Wied. Ann.*, 3, 251.

[4] "Ueber almähliche Ueberführung des Bandenspectrums des Stickstoffs in ein Linienspectrum."—*Wied. Ann.*, 8, 590.

However, these observations were all but certainly illusive, as others have asserted, and as will be explained further on, and the theories are at least incomplete since they do not agree in all respects with observations. In considering them I shall confine myself to those parts that deal with the displacements or shifts of the lines.

According to Lommel's theory the spectral lines increase in width, chiefly on the red side, and shift in the same direction when the density of the gas producing them is increased. He says: "Bei vergrösserung der Dichte oder des Drucks eines Gases erleidet die helle Spectrallinie eine Verbreiterung und gleichzeitige Verschiebung nach der weniger brechbaren Seite hin."

This theory makes the spreading of a line and its displacement depend upon the same thing — namely, the increase of the density of the gas whose lines are affected. According to it the spreading must always be chiefly towards the red end of the spectrum, and the lines must shift only when they are spread out; in fact the shift of a line is due, in terms of the theory, to unsymmetrical broadening and to nothing else.

As a matter of fact, while many lines are spread out, by increase of the density of the gas producing them, chiefly towards the red end of the spectrum, many others are broadened symmetrically, and others even spread out chiefly towards the more refrangible or violet end. Therefore by merely increasing the density of the luminous gas or vapor, without change of total pressure, the centers of certain lines are moved toward the red and others toward the violet of the spectrum; while those lines that spread symmetrically are not displaced at all. Besides the reversals, which of course give the positions of the most intense portions of the lines, are never displaced in the slightest by any increase in the density of the luminous gas or vapor so long as the absolute pressure is kept the same.

The shift discussed in this paper probably does not depend in the least, as will appear from the experimental results, upon the density of the gas or vapor producing the lines, but only

upon the absolute pressure; and apparently it has no connection with the spreading, either symmetrical or unsymmetrical, of the lines themselves. It would therefore seem that Lommel's theory, though ingenious and well worked out, in no wise predicts the observations described in the following pages.

In support of that part of his theory which demands a shift of the lines, Lommel refers to the experiments of Zöllner[1] and Müller,[2] both of whom used the common method of putting a bead of salt in a Bunsen flame and then examining, by suitable methods, the light so produced. The intensity of the flame and the quantity of salt in it were both varied, and some of the results they obtained indicated a movement of the lines towards the red end of the spectrum. This can be explained by, and was almost certainly due to, unsymmetrical spreading of the lines examined. Certainly neither observer found (the conditions were not such as would produce it) a true displacement of the lines in the sense that the term is used in this paper. That is, they did not find a given line, produced under certain conditions, differing from the same line when produced under other conditions in any wise except mere position in the spectrum; nor do they speak of the displacement of the reversals.

The other theory referred to, that of Wüllner, assumes all variations in the spectrum of a substance to be due to what might be termed external changes, such as temperature, density, and the like, and in no case, not even in the change from band to isolated line spectra, to any alteration of molecular grouping. Wüllner assumes the correctness of Zöllner's equation,

$$E = \left\{ 1 - (1 - a)^{d\delta} \right\} e,$$

in which E is the total amount of light of a given wave-length, d the thickness, δ the density, a the coefficient of absortion of the luminous gas or vapor, and e the power of a perfectly black

[1] "Ueber den Einflus der Dichtigkeit und Temperatur auf die Spectra glühender Gase." *Pogg. Ann.*, 142, 88.

[2] "Beobachtungen über die Interferenz des Lichtes bei grossen Gangunterschieden." *Pogg. Ann.*, 150, 311.

body, at the same temperature as the luminous gas, to give out light of the given wave-length. If a is a function not only of wave-length but of temperature too, and such a function of them that its maximum value occurs at different places for different temperatures, as Wüllner assumes it to be, then clearly a line may be shifted by merely changing the temperature of its source. Besides, the shift may be in either direction and may be regular or irregular. In short, if a is such a function of temperature and of wave-length as that just described one can only say that a given change in temperature will produce a greater or less change, in one direction or the other, in the position of a line in the spectrum. In certain respects the conclusions of this theory are not supported by careful observations, and for this reason it is not now, if ever, well received by spectroscopists. In regard to the displacements of the lines it is stated by Kayser,[1] in an article in which he discusses the above theory quite fully, that he knows of only one line, D_2, of which accurate measurements have indicated a shift, and that in this case the shift is illusive, and due to unsymmetrical broadening. His words are: "Mir ist nur ein Fall bekannt wo man nach genauen Messungen eine Verschiebung glaubte beobachten zu können: nämlich bei der Linie D_2; aber dies ist, wie an anderer Stelle gezeigt werden soll, eine Täuschung: D_2 verbreitet sich nicht gleichmässig nach beiden Seiten, daher scheint sich die Mitte etwas zu verschieben, aber der hellste Theil, die eigentliche Linie bleibt genau an ihrer Stelle." In another place[2] Kayser says that neither lines nor bands have ever been observed to shift. "Eine Verschiebung von Linien ist selbst von den genauesten Messungen niemals beobachtet worden, weder beim Banden- noch beim Linienspectrum."

Before the present work was begun no accurate experiments, so far as I can learn, had shown a true shift independent of all other changes of the spectral lines, nor had it been demanded by theory. Lommell's theory made the shifts of the lines a conse-

[1] "Ueber den Ursprung des Banden- und Linien Spectrums." *Wied. Ann.*, 42, 310.

[2] WINKELMANN, *Handbuch der Physik*, II, 1, p. 425.

quence of their unsymmetrical spreading, while Wüllner's theory, though capable of explaining any one of several phenomena, is too flexible to predict shifts of lines at all definitely. It only states in this particular what is perfectly evident, namely, that by changing the conditions under which the spectrum of a substance is produced its lines may or may not be displaced, which of course is really predicting nothing.

As stated above, neither of these theories has been supported as to the shifts of the lines by observations. Instead then of regarding the wave-frequency of a line, and consequently its wave-length and position in the spectrum, as being one thing or another, owing to circumstances, practically all spectroscopists have considered it a constant of reference (except as modified by the Doppler effect), subject to no possible change. All observers who have given us tables of accurately determined wave-lengths have, at least tacitly, made this assumption, and upon it are based the estimates of the velocities in the line of sight of many of the fixed stars. The same assumption is made in comparing solar and stellar with terrestrial spectra for the purpose of determining the constituents of the Sun and stars, and when the coincidence of lines evidently the same was not exact the discrepancy was naturally referred to some cause other than actual change in wave-length.

This assumption of the constancy of wave-frequency has led to the hope, a vain one it seems, that wave-lengths of spectral lines may serve as ideal units of reference — units whose values are absolutely the same at all times and under all circumstances.

While the wave-frequencies of spectral lines depend, as shown further on in this paper, upon the physical conditions under which they are produced and therefore their wave-lengths are not ideal units of reference, still it is easy to obtain spectral lines, as often as desired, under conditions so similar that their wave-lengths are more nearly ideal length units than are those which we can at present obtain in any other way. Consequently the results of the experiments described in the following pages do not materially affect (though they show precautions that must

be taken) the value of Professor Michelson's[1] most ingenious and careful determination of the wave-lengths of the red, green, and blue lines of the spark-spectrum of cadmium vapor at low pressure, in terms of the standard meter.

OBJECT OF THE INVESTIGATION.

The work described in this paper was suggested by Dr. Ames and begun for the purpose of examining minutely the effect of pressure on the arc spectra of various elements, and in particular for noting the effect if any on the wave-lengths of the lines. The idea of examining arc spectra under pressure occurred to Professor Rowland several years ago, and the apparatus used in the present investigation is that which he had constructed for this purpose. Constant work however along other lines prevented him from making any observations with it.

The first accurate observations, to the best of my knowledge, that suggested the probability of a functional relation between the wave-frequencies of spectral lines and the conditions under which the lines are produced were made by Mr. L. E. Jewell in the physical laboratory of the Johns Hopkins University. The suggestion came in part from the fact that Mr. Jewell's numerous and careful measurements of the same lines in the arc and solar spectra showed a want of coincidence which varied for different elements. While this want of coincidence was never great, still it seemed too regular to admit of the apparently obvious explanation that it was not due to any real difference in wave-length, but to some disturbance of the apparatus during the exposure of the photographic plate. Mr. Jewell had also obtained slight real or apparent displacements of certain lines by changing the amount of material in the arc. It was this chiefly that led Dr. Ames to suggest the present investigation.

The only way, of course, to determine whether such a functional relation between wave-lengths of spectral lines and the conditions under which the spectra are produced actually exists,

[1] "Determination experimental de la valeur du mètre en longueurs d'ondes lumineuses."

was by direct experiment, and it therefore seemed advisable to examine arc spectra under different conditions, especially of pressure and so far as possible of temperature too, since the conditions under which solar and ordinary spectra are produced may differ greatly in both these respects.

Another reason for taking up this investigation was found in the fact that the wave-lengths of the red, blue, and green cadmium lines as determined by Professor Michelson for the purpose of accurately comparing them with the standard meter, were less in each case than those of the same lines as determined by Professor Rowland. These differences are .208 of an Ångström unit for the red, .173 for the green, and .186 for the blue line. In each case the difference amounts to only about one part of the wave-length in thirty thousand, and in itself is not very surprising, since the methods followed by these two able men were totally different; but it is rather surprising that these differences are not constant. Here again differences of physical conditions under which the spectra were produced (Michelson worked with spark spectra at low pressure, while Rowland used the arc at atmospheric pressure) suggest a possible explanation of the want of agreement in their measurements. The results of numerous examinations of cadmium spectra as produced under different pressures do account for a part, though only about 5 per cent., of the above differences, but fail to suggest, at least very definitely, why the differences should not be the same for all the lines.

APPARATUS USED.

The grating used in all this work was a six-inch Rowland concave of twenty-one and a half feet focal length and ruled with 20,000 lines to the inch. It was mounted in the usual way, as fully described by Dr. Ames in the Johns Hopkins *Circular* of May 1889. The arc was produced by a direct 110-volt current of any amperage desired. It was found necessary to make the strength of the current very different for different substances and also for different amounts in the arc of the same substance. At times the current was small — only a few amperes—while occasion-

ally, judging from the fuses blown and other effects, it was little if any less than one hundred. The effect of varying the strength of the current will be discussed further on. The poles of the electric arc were used vertical and parallel to the slit of the spectroscope. Horizontally mounted poles were also tested, and the results will be given in the proper place, but it did not appear necessary to use any other than the vertical mounting, which was found to be much the more convenient of the two tried.

A number of photographs were taken of the spectrum given by an arc between one carbon and one (the lower) metallic pole, and a few of the spectrum formed by an arc between two metallic poles. The metals so used were iron, copper, brass and zinc. In all other cases both poles were of carbon, the lower one being bored axially to a depth of from one to three inches. This cavity, which was about an eighth of an inch in diameter, was filled with the substance or substances whose spectrum was desired. Very often elements were used in the metallic form, but as a rule it was more convenient and occasionally, as in the case of sodium and potassium, much better to use some compound. The quantity of the element or compound in the arc could easily be reduced, as was often necessary, by mixing it with carbon dust before charging the pole with it. In nearly all casest he pole carrying the charge was made the positive one.

The pressure around the arc was obtained in every instance by pumping air into the apparatus designed for this work by Professor Rowland, as stated above, and used by Messrs. Duncan, Rowland and Todd[1] in their examination of the electric arc under pressure. The structure of this apparatus may be understood by aid of the accompanying sketch, Fig. 1, in which A is an iron cylinder fourteen inches high and seven inches in diameter. B, B are suitably constructed stuffing boxes through which the rods C, C pass practically air-tight. These rods are insulated from the smaller rods H, H which they contain, and which carry the carbons. N is the negative and P the positive

[1] *Electrical World*, 22, 1893.

pole as commonly used. The latter is represented partly in section to show the cavity S in which the substance whose spectrum is desired is placed. The carbon N can be raised and lowered by means of the rack R and pinion G, and the carbon

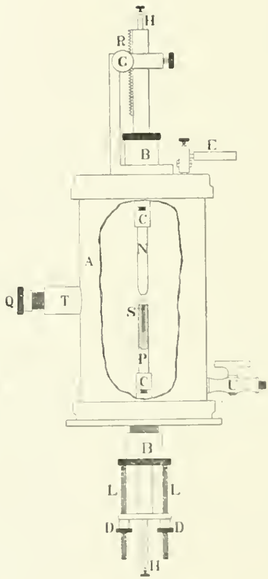

Fig. 1.

P can be brought to the proper position with the nuts and screws D, D and L, L. The light reaches the slit of the spectroscope by passing through the side tube T, which is closed at Q with a plane quartz disk. The object in using quartz instead of glass is of course to avoid, as far as possible, the absorption of the ultra-violet light. The air is pumped in through the tube U, which can be opened and closed by means of the stopcock V.

and the pressure is given by a Bourdon gage *E*, reading from one to twenty atmospheres.

METHOD OF PHOTOGRAPHING.

For the purpose of accurate comparison it was necessary to obtain side by side photographs of the spectra of the substance in question as given by the arc under the two pressures used, the lowest of which was always that of one atmosphere. It was also necessary to guard, as far as possible, against any accidental movement of the camera or other part of the apparatus during the exposure and to be able to surely detect any such accidental disturbance should it occur, since any slight movement of the apparatus during, and especially between successive exposures on the same plate, would necessarily lead to false results.

The first of these requirements, that is the obtaining of the spectra in such way that they could be accurately compared, was met in the same manner (and with the same apparatus) that Professor Rowland met a similar requirement in the comparison of solar and arc spectra, that is by providing the camera, which takes a nineteen by one and a quarter-inch plate, with a rotating shutter so constructed that in one position it shields the sides along the entire plate and leaves a narrow middle strip exposed, while in a certain other position it shields the middle strip and exposes the sides. In nearly every case the middle strip was exposed to the arc under pressure, after which the air was let out from the cylinder, the shutter adjusted and the sides of the plate exposed to the arc at atmospheric pressure.

The method used at first for detecting accidental disturbances was as follows: By means of an auxiliary shutter a small portion of the middle strip was exposed to the solar spectrum, all other parts of the plate being shielded, then the remainder of this strip to the arc under pressure, then the corresponding sides to the arc at atmospheric pressure, and finally the remaining portions to the solar spectrum. This process secured a short section of solar spectrum, the middle portion of which was exposed

before, and the sides after the exposures to the arc. Consequently any disturbance of the apparatus between the first and and last exposures was shown by breaks in the solar lines. It soon became evident, however, that this method, though accurate, was not necessary, since the lines of the carbon bands, some of which occur on nearly every plate, are never measurably displaced, and therefore serve perfectly to detect any disturbance of camera or other part of the apparatus during or between the exposures.

METHOD OF MEASURING.

The shifts of a few lines were determined by direct observations with a micrometer eyepiece, but in all other cases the measurements were carefully made on photographs with a most accurate dividing engine especially constructed by Professor Rowland for this sort of work, and used in determining Rowland's Table of Standard Wave-lengths. The dividing engine and the micrometer eyepiece are both constructed to read directly to hundredths of a millimeter, and may be estimated to thousandths of a millimeter.

Most of the plates were taken in the second spectrum, where the dispersion is a little more than one millimeter per Ångström unit, though a few were taken in the first, where the dispersion is one-half that of the second, and many in the third, where it is three halves that of the second. In all several hundred negatives were secured and the shifts determined of those lines whose positions were well defined by reason either of their sharpness or of their reversals.

To facilitate the measuring of the shifts and at the same time to increase the accuracy a system of double cross-hairs was placed, as shown in Fig. 2, in the field of the microscope. In the process of measuring the microscope was kept fixed and the negative moved along by the micrometer screw until the cross *a* was on the center of a given line in the middle strip, that is a line produced by the arc under pressure, when a reading was taken. The plate was then moved forward by the screw

until the crosses *bb* were on the center of the same line as formed on the sides of the plate by the arc at atmospheric pressure, when another reading was taken, and so on for other lines. The plate was then reversed and the same process repeated.

Let s be the shift of any line, and l the difference in readings that would be given by the crosses a and *bb* when there is no

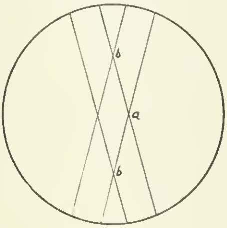

FIG. 2.

shift, and let the direct reading of the crosses *bb* be λ and the reversed d. By "direct reading" is meant that which is obtained when the plate is being moved so that the successive lines to come into the field of the microscope are of increasing wave-length, and by "reversed reading" that obtained when the plate is moving so that the successive lines seen through the microscope are of decreasing wave-length. The direct reading, therefore, given by a is $\lambda - l \pm s$, and the reversed $d - l \mp s$. Evidently $\lambda + d$ is a constant for all the lines on any one plate, from which, if the reversed readings be subtracted, remainders, "corrected reversed," will be obtained equal respectively to λ and $\lambda + l \pm s$. Consequently for any one line the average of the two readings "direct" and "corrected reversed" given by the crosses *bb* is λ, and that of those given by the cross a, $\lambda \pm s$, their difference being the shift $\pm s$. By this means the accuracy of the measurements is rendered quite considerable. In the case of extra good lines the error should not exceed from two to three thousandths of an Ångström unit.

EXPERIMENTAL RESULTS.

A little preliminary work was done with the arc spectra, at atmospheric pressure, of cadmium and a few other elements. The chief changes found were those of intensity and width of the lines, both of which increased with increase of material. A large amount of material in the arc caused the reversal of many lines, but in every case examined the reversal coincided very closely if not exactly with the position of the corresponding fine lines as produced by a small amount of the substance.

The element whose spectrum as formed under pressure was first examined was cadmium, and it was at once noticed that the positions of its lines were very appreciably changed by a pressure of even three or four atmospheres. Subsequently the lines of a large number of other substances were similarly examined, and in every case their positions, except those of lines of certain bands, were more or less changed.

That this change in position of the lines is not due to any strain or movement of some portion or other of the apparatus may be shown in several ways, but it is easiest and also best shown by the fact that on the same plate lines due to different substances are displaced to very different extents, whereas they should be equally displaced if the displacement were due to a disturbance of the apparatus while photographing. Nor is the observed shift of the lines due to unsymmetrical broadening, since in many cases equally fine and sharp lines were obtained at high and normal pressures, the only important difference between the lines as obtained under the two conditions being that of position. Not only were numerous lines of this character photographed, but the evidence as furnished by the negatives was also checked and confirmed by a number of eye observations, especially on the cadmium lines λ 6438.680 and λ 5086.001, and the sodium lines D_1 and D_2. By filling the positive pole with fused potassium sulphate, which usually, like the specimen used, contains more or less sodium, it was easy at any pressure, up to ten or more atmospheres, to get the sodium lines D_1 and D_2, and to retain

them some minutes as beautifully fine and sharply reversed lines, differing in no respect from the same lines as obtained at very different pressures except quite decidedly in position. A further reason for the statement that the shift is not due to unsymmetrical broadening is found in the fact that the wave-lengths of all fine and sharp lines, and also of the reversals of heavy ones, increase with increase of pressure around the arc, no matter how the lines may spread out, symmetrically or chiefly towards either side. A splendid example of this is furnished by the pair of sodium lines λ 3302.504 and λ 3303.119. These lines are quite unsymmetrical — spreading chiefly towards the violet or more refrangible end of the spectrum — but their reversals are greatly shifted in the opposite direction. Neither is the shift due to the disappearance of one line and the appearance of another of slightly different wave-length, because the wave-length increases regularly and not by jumps as the pressure is increased; and, besides, it is not difficult to observe, while the pressure is being slowly let off, either a fine line or the reversal of a heavy one gradually change in position without alteration in width or any other respect.

It has been suggested by Schuster[1] that this shift of spectral lines is possibly due to the "proximity of molecules vibrating in equal periods." If this supposition is correct, then, of course, the shifts of the lines should be greater at any given pressure, as Schuster says, the greater the amount of material used that produces them. However, many experiments both before and since the appearance of Schuster's paper show that this is not the case. Among the substances that have been most fully tested in this respect are iron, titanium, copper, and zinc. The carbons used, though reasonably pure, contained a considerable number of impurities in sufficient amounts to give some of their strongest lines, and among these substances were iron, titanium, and copper, each of which gave some very fine but quite measurable lines. The amounts of these substances were then gradually increased until they were as great as possible. In the case of

[1] *Ap. J.*, April 1896.

iron, copper, and zinc, solid rods of the metals were finally used, but in every instance the shift of a given line of any substance remained constant for any definite pressure, showing that it depends upon the absolute pressure and not upon the partial pressure of the gas or vapor producing the line in question.

More recently it has been suggested by Fitzgerald[1] that a "*vera causa* for some shift towards the red in molecules causing light" is the increase of the specific inductive capacity, due to increase of density, of the gas surrounding the arc. This suggestion is based, of course, upon the assumption, possibly a correct one, that "electric forces are at least a part of the forces affecting the periods of vibration." The correctness of this suggestion has not been submitted to actual experimental tests, nor does it seem very easy to do so, at least not directly, since the differences in the specific inductive capacities of gases are not sufficient to produce changes in the shifts greater than the errors of observation, even if the shifts are due entirely to the cause suggested. No matter what theory or suggestion is advanced, it must be remembered that it is imperfect if it does not account in some way for the important fact that at least many elements produce two or more groups of lines, differing greatly from each other in the magnitude of their shifts.

If, as many believe, the temperature of the electric arc is that of boiling carbon it would seem natural to suppose that it would rise with increase of pressure. Very little seems to have been done to test this point, but a number of experiments as conducted by Wilson,[2] and later by Wilson and Fitzgerald[3] have given conflicting results. However, whether pressure causes an increase or a decrease of temperature, in either case the shifts of the spectral lines may conceivably be due to a change in temperature rather than pressure, and experiments were undertaken to clear up this point. In accordance with Wilson and Gray's[4] work, which indicates that the temperature of the negative pole is much less than that of the positive, a long arc, due to a fairly

[1] *Ap. J.*, March 1897.

[2] *Proc. R. Soc.*, May 30, 1895.

[3] *Ap. J.*, February, 1897.

[4] *Proc. R. Soc.*, November 24, 1894.

heavy current, was formed at right angles to the slit of the spectroscope, and one part of a photographic plate exposed to the spectrum due to the arc close to the positive and the other part to the spectrum as formed by the arc near the negative pole. No change, however, was detected in the position of the lines. Another method of testing the same point was to vary between wide limits the strength of current used, since the temperature, according to Moissan,[1] probably rises with increase of current. The extreme currents used were two amperes and 180 amperes respectively, but the positions of the lines appeared to remain absolutely unchanged. Further tests were made on the sodium line D_2 (one of the most sensitive of all lines examined) as produced first in the Bunsen flame and then in the electric arc; but while the temperatures of the vapor in the two cases were probably widely different the position of the line remained the same, as nearly as could be determined. Again one would certainly expect the outer envelope of an electric arc to be much cooler than the core, but the position of a reversal given by the former is exactly the same as that of a fine sharp line produced by the latter. The expression, "temperature of the arc or flame," is used with hesitation, since so little is known of the mean condition of the molecules producing light, but the negative results of all the above experiments give every assurance that the shifts of the lines are not ordinary temperature effects. It should be stated, however, that the luminous intensity of the arc greatly increased, especially where metallic poles were used, with increase of pressure.

The numerous negatives obtained, as well as the eye observations made, show that the general effect of pressure is to broaden the lines and to bring out their reversals. However, this is not always the case, since lines often appear quite as fine and sharp at one pressure as at another; and in all probability the broadening of the lines is due, chiefly at least, to an increase of density of the gas producing them, since it is always greater the greater the amount of the substance used in the arc. This

[1] *Annals de Chimie et de Physique*, October 1896, p. 231.

idea is also in accord with Schuster's[1] observation that when gases are mixed in different proportions the lines of any one become sharper when it is present in smaller quantity, though the total pressure may remain the same.

The lines of the cyanogen bands came out more strongly on my plates under pressure (the pressure being due to atmospheric air), but never showed much if any shift, which fact furnished conclusive evidence that the shifts of other lines were due to real changes in wave-frequencies and not to some disturbance of the apparatus, since they were all photographed simultaneously on the same plate, the lines of the cyanogen bands never being appreciably displaced while other lines were.

The shift or displacement of any line is directly proportional to the excess of pressure above one atmosphere (the position of the line as formed at atmospheric pressure being taken as its normal or zero position) and is always towards the less refrangible or red end of the spectrum. The same law has been shown by Mohler[2] to hold for pressures below one atmosphere—the shift in this case being to the violet. The shift is very different for the lines of different elements, and also, in many cases at least, for different groups of lines of the same element. In particular the shifts of the several series of lines (as given by the alkalies), principal and subordinate, are by no means equal, even when the lines are of approximately the same wave-length, as shown by the tabulated results in Table I. Lines of the second subordinate series seem to shift about twice as much as those of the first, which in turn are displaced to an extent approximately twice that of the lines of the principal series. A few iron lines, each of which is more hazy or softer than the average line of this element, are shifted about three times as much as other lines of the same substance. Again, all the nebulous or hazy copper lines examined shift to approximately the same extent (allowance being made for wave-length) but much more than do other lines of the same element. It is worth noting that these nebulous lines of copper were best obtained when both poles of the

[1] *Ency. Brit.*, "Spectroscopy."

[2] *Ap. J.*, October 1896.

arc were metallic rods, brass and copper or both copper, and that apparently the only effect of pressure on them was to greatly increase their wave-lengths. In this connection mention must be made of the calcium line *g*, which is shifted about twice as much as the similar calcium lines H and K. The same thing is also true of the three corresponding lines of strontium and of barium.

Similar lines of any given element, that is, lines belonging to the same series, or to no series but of the same character, shift to extents proportional to their wave-lengths. The most conclusive evidence of this proportionality was furnished by lines of different orders of spectra that appeared on the same plate. Thus ultra-violet lines of the third order were often found on the same plate with similar lines of the second of longer wave-length but due to the same element, and their measured shifts were approximately the same. Since the wave-length of a line of the third order is to that of one of the second that occurs at the same place as two to three, while the dispersion in the third order is to that in the second as three to two, it follows that constancy of measured shifts means that it is proportional to wave-length. For the sake, therefore, of comparison it seemed advisable to reduce the shifts of all lines to what they would be at some definite wave-length ; the one chosen being 4000 Ångström units, since most of the work was done in that neighborhood.

It should be stated that in some cases the values obtained for the shifts of the lines may have been due in a measure to unsymmetrical broadening; but this has certainly not led to much error, since as already stated, only those lines were used which could be fairly accurately measured, that is, those which were either comparatively narrow or else reversed.

DESCRIPTION OF TABLE I.

The results of the numerous measurements are given in Table I, in which the uppper numbers in the line of each wave-length are the observed shifts in thousandths of an Ångström unit, and the lower their values reduced to wave-length 4000. In many cases the observed shift, as given, is the average of fairly con-

cordant measurements of the same line on different plates. The different pressures used are given in atmospheres at the heads of the columns, and are greater by unity (since the lower pressure of each experiment was always one atmosphere) than the difference in pressure, $p-p_0$, to which the shift was actually due.

In most cases the wave-lengths are taken either from Professor Rowland's Table of Solar Spectrum Wave-lengths, in process of publication in the ASTROPHYSICAL JOURNAL, or from a former table of his published in *Astronomy and Astro-Physics*.[1] Some are taken from the papers of Kayser and Runge, and a few from other sources, but it was found necessary, for the want of suitable tables, to determine a number of them by comparison with known lines in their neighborhood, and since exact wave-lengths are not essential to this work, only such approximations of them are given as will serve to surely identify the lines in question.

TABLE I.

Showing the pressure in atmospheres and the observed resulting shifts ($\Delta\lambda$) in thousandths of an Ångström unit, and the same reduced to wave length 4000.

ALUMINIUM.

Wave-length λ	$\Delta\lambda$ observed and Pressure in atmospheres, followed by $\Delta\lambda$ reduced to λ 4000										
	$4\frac{1}{4}$	$4\frac{3}{4}$	6	7	$7\frac{1}{2}$	9	$10\frac{1}{2}$	$10\frac{3}{4}$	$11\frac{3}{4}$	$12\frac{1}{4}$	14
3082.27 . .				38 50		38 50					
3092.84 .				40 52		38 50					
3944.114 .		17 17	29 29					44 45	49 50	48 49	68 69
3961.674 . .	17 17	25 25	26 26	37 37	36 36		44 45	40 41	57 58	52 53	70 77
Average.	17 17	21 21	28 28	38 40	36 36	38 50	44 45	42 43	53 54	50 51	72 73

NOTE.—Several lines of the aluminium oxide band, 4842–5041, were measured on two plates which were taken at different pressures. The shift, if anything, was very small.

[1] *A. and A.*, 12, 1893.

TABLE I.—*Continued.*

ANTIMONY.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
				6¾			
3267.6				26 21			

BARIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
	7	8	8½	10	10½	11	12
4432.13	41 45						71 78
4506.11	32 36					50 56	61 69
5535.69	23 32	38 52		40 56	50 68		58 80
Group A.							
Average	32 38	38 52		40 56	50 68	50 56	63 76
4554.211	20 23		21 24	28 32	30 34	35 40	
4934.237			19 23	28 34			
Group B.							
Average	20 23		20 24	28 33	30 34	35 40	
3910.04							120 117
3935.87							121 119
3993.60							126 126
4726.63							115 135
Group C.							
Average							120 124

TABLE I.—*Continued.*

ARSENIC.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
			8½	9	10		
2745.09					29 / 20		
2780.30					32 / 22		
2860.54					28 / 20		
2898.83			28 / 20	25 / 18			
Average			28 / 20	25 / 18	30 / 21		

BERYLLIUM (GLUCINUM).

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
				7½			
3130.6				14 / 11			
3321.3				24 / 19			
3321.5				24 / 19			
Average				21 / 16			

BORON.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
		8	8½	9	9¼		
2496.867		30 / 19	37 / 23	37 / 23	40 / 25		
2497.821		30 / 18	30 / 18	35 / 22			
Average		30 / 19	34 / 21	36 / 23	40 / 25		

TABLE I.—*Continued.*

BISMUTH.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
			10	13½			
2898.08			26 35				
2989.15			34 45				
3397.31				48 57			
Average			30 40	48 57			

CÆSIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
			6	7			
4555.44			138 121	123 108			
4593.34			95 82	78 68			
Average			117 102	101 88			

CARBON.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
		8	8½	9	9¼	10	
2478.661		24 38	20 32	24 38	23 38	26 42	

NOTE.—A number of "cyanogen" lines were measured at various pressures, and found to shift very little, if at all.

TABLE I.—*Continued.*

CADMIUM.

Wave-length λ	$\Delta\lambda$ observed and Pressure in atmospheres, followed by $\Delta\lambda$ reduced to λ 4000						
	7	7½	8	9	9½	10	10½
3261.17					18 22		
3466.33					20 23		25 28
3610.66						20 22	
No series.							
Average					19 23	20 22	25 28
6438.680	Reduced to λ 4000 and for a pressure of 12 atmospheres $\Delta\lambda$=80.[1]						
3403.74					29 34		25 30
3467.76					27 31	18 21	20 23
3613.04					16 18	19 21	
First subordinate series.							
Average					24 28	19 21	23 27
3081.03	40 53			60 80			
3133.29	48 60			51 65			
3252.63		31 38			47 57	56 69	
4678.347				54 47	79 68		
4800.080			43 36	48 40	70 58		
5086.078	53 42	59 47	63 50	67 54	70 56		82 66
Second subordinate series.							
Average	47 52	45 43	53 43	56 57	67 60	56 69	82 66

[1] Mean of several concordant eye observations by different persons and at different pressures.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000: 3	4½	5	6	7	8	9	10	10½	11	12½	14½
K 3933.825									25 / 25	24 / 24	28 / 28	
H 3968.625									22 / 22	26 / 26	33 / 33	
4283.169			12 / 13	17 / 18		27 / 29				29 / 31	28 / 30	
4289.525			15 / 16	16 / 17		19 / 20				33 / 35	38 / 40	
4299.149		8 / 8	16 / 17	12 / 13		20 / 22				33 / 35	32 / 34	
4302.692				11 / 12		25 / 27				28 / 31	27 / 30	
4307.91				25 / 27						27 / 30		
4318.80						25 / 27		22 / 24		27 / 30		
Group A Average		8 / 8	14 / 15	16 / 17		23 / 25		22 / 24	24 / 24	28 / 30	31 / 33	
3158.98						53 / 42	60 / 47					
3179.45						47 / 37						
g 4226.904						40 / 42		45 / 48		48 / 51	53 / 56	82 / 87
4435.13[1]										74 / 81		
4454.97[1]										73 / 80		
5588.985					47 / 66		49 / 68			50 / 70		
5594.691					47 / 66		57 / 80			52 / 72		
5598.711					49 / 68		55 / 74			47 / 63		
5603.083						40 / 56						
Group B Average					48 / 67	45 / 44	55 / 67	45 / 48		57 / 69	53 / 56	82 / 87
4425.61										76 / 84		
4435.86										80 / 88		
4456.08										71 / 79		
1st subordinate ser. Average										76 / 84		
6102.99	44 / [2]67		77 / [2]117			109 / [2]166	133 / [2]203					
6122.46	35 / [2]53		53 / [2]82			91 / [2]140			141 / [2]215			
6162.46		55 / [2]84					96 / [2]148		139 / [2]214			
2d subordinate ser. Average	40 / 60	55 / 84	65 / 100			100 / 153	115 / 176		140 / 215			

[1] Occurs with lines of 1st subordinate series, and shifts to the same extent. [2] Eye observations.

CERIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000					
			6½	8		
3895.224			21 20			
3896.917			14 14			
3898.4			23 22			
3912.5			17 17			
3917.7			13 13			
3918.4			8 8			
3919.9			20 20			
3921.6			22 22			
3929.3			17 17			
3931.2			17 17			
3940.4			19 19			
3941.1			8 8			
3949.2				8 8		
3953.7			8 8			
3955.4			10 10			
3957.4				15 15		
3961.0			7 7			
3964.6			6 6			
3971.8			12 12			
3972.2			17 17			
3975.1			19 19			
3978.7			7 7	9 9		
3984.7			12 12			
3989.5			11 11			
3992.5			15 15	21 21		
3993.0			17 17			
Average			14 14	13 13		

TABLE I.—*Continued.*

CHROMIUM.

Wave-length λ	Δλ observed and Pressure in atmospheres, followed by Δλ reduced to λ 4000											
	4¾	6	7	9¾	10	10½	11	11½	12¼	12½	14	14½
	4						26				36	
3886.932..	4						27				37	
		16					20			12	29	
3919.309..		16					20			12	30	
	7						33				32	
3941.637..	7						34				33	
	7	12	16	25		23	27			36	47	
3963.831..	7	12	16	25		23	27			36	47	
	14	12	12				28				38	
3976.839..	14	12	12				28				38	
	12						34				49	
3984.059..	12						34				49	
			19									
4026.318..			19									
	3	9	19				26				26	30
4254.505..	3	9	18				24				24	28
					17							
4266.894..					16							
	14	11					31		24		40	31
4274.958..	13	10					29		22		38	29
							30	23				
4280.556..							28	22				
							34				41	
4289.885..							32				44	
	9	14	16	25	17	23	29	23	24	24	38	31
Average	9	13	15	25	16	23	28	22	22	24	37	29

COLUMBIUM (NIOBIUM).

Wave-length λ	Δλ observed and Pressure in atmospheres, followed by Δλ reduced to λ 4000						
			8½	9½			
				27			
3914.8				28			
				13			
3937.7				13			
			22	24			
4059.0			22	24			
			30	32			
4079.9			29	31			
			26	24			
Avearge			26	24			

TABLE I.—*Continued.*

COPPER.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000											
	7		8		12¼		12½		13		13½	
2883.03	8	11	7	10								
3010.92	11	15										
3036.17	9	12										
3073.89	7	10										
3094.07	13	17										
3247.680					25	30	28	33			28	33
3274.092					20	25	32	38	30	36	36	41
3317.28			13	16								
3337.095	11	13	11	13								
3476.07	8	10	14	16								
3483.82	12	14	17	19								
3520.07	16	18										
3524.31	12	14	19	21								
3533.84	13	15										
3545.05	17	19										
3590.20	15	17	17	19								
3621.33	10	11										
3636.01	16	18										
3684.75	13	15										
5105.75			20	16								
Lines of small shift. Several others of this set were measured												
Average	12	14	15	16	23	28	30	36	30	36	32	37
3365.46	27	32	28	33								
3381.52	24	28										
3620.47	36	40										

TABLE I.—*Continued.*

COPPER—*Continued.*

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000					
	7	8	12¼	12½	13	13½
3741.32	38 35					
3860.64	37 35					
5218.45		33 43				
Lines of medium shift						
Average	35 31	33 36				
4177.87	83 87					
4249.21	54 57					
4275.32	60 64					
4378.40	74 81					
4415.79	73 80					
4587.19	64 74					
5292.75		52 68				
Lines of large shift. Several others belong to this set. Most of these lines are "soft" and broad						
Average	68 74	52 68				
5153.33		21 27				
5220.25		23 30				
First subordinate series						
Average		22 29				
4480.58	44 50					
4531.04	46 53					
Second subordinate series						
Average	45 52					

TABLE I.—*Continued.*

COBALT.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000			
	9¾	11¼	12½	14½
3354.515			19 23	33 39
3361.413			18 22	
3395.016			20 24	22 26
3405.255	17 20			
3409.336	14 16			23 27
3417.384			23 27	29 34
3461.326	18 21			
4121.476		20 19		
Average	16 19	20 19	20 24	27 32

ERBIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000
	8
3988	30 30

GERMANIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000		
	7	8½	9
3039.198		22 29	24 31
3269.628		24 29	22 27
4226.724	30 28		
Average	30 28	23 29	23 29

TABLE I.—*Continued.*

GOLD.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
			7	10	10½		
3122.88					20 26		
3898.04					40 41		
3909.54					25 26		
4041.07			20 20	25 25			
4065.22			34 33	34 33			
Average			27 27	30 29	26 29		

INDIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
	7	9½	10	10½	11½	12½	14½
3256.17 No series		19 23	23 28				
3258.66 1st subordinate series		36 44	37 45				
2932.71	43 60						
4102.00					69 68		
4511.345 2d subordinate series		73 65	83 74	81 72		102 90	125 111
Average	43 60	73 65	83 74	81 72	69 68	102 90	125 111

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000													
	4½	6	7	9	10	11	11¼	11½	12¼	12½	12¾	13	14	14½
3997.547 . .							29 / 29							
4005.408 .			15 / 15		23 / 23	32 / 32								
4009.864 .					18 / 18									
4045.975 . . .	8 / 8	9 / 9					20 / 20							
4063.759 . . .							23 / 23							
4181.919 . . .					26 / 25									
4199.267 . .					25 / 24									
4207.291 . . .					18 / 17									
4219.516 . .					18 / 17									
4236.112 . . .	8 / 8		17 / 16			26 / 25								
4250.945 . . .			11 / 11		26 / 25	31 / 29				35 / 33	25 / 24		34 / 32	
4271.934 . . .	8 / 8	13 / 12	14 / 13			25 / 23	28 / 26	20 / 19	28 / 26	23 / 22	26 / 24		30 / 28	30 / 28
4294.301 . . .					25 / 23									
4298.195 . . .					26 / 24									
4325.930 . . .							26 / 24				32 / 30	35 / 32	34 / 31	
4377.948 . .								21 / 19						
4382.928 .					24 / 22				26 / 24		27 / 25	35 / 32		31 / 28
4383.720 . .								28 / 26						
4404.927 . .								23 / 21						
Many other lines belong to this group														
Average .	8 / 8	11 / 11	14 / 14		23 / 22	29 / 27	25 / 24	23 / 21	27 / 25	29 / 28	28 / 26	35 / 32	32 / 30	31 / 28
4222.382 .									70 / 66					
4227.606 .									77 / 73					
4233.772									79 / 75					
4236.112 .			26 / 25	59 / 56	60 / 57				79 / 75					
4250.287 .			57 / 54	95 / 90	84 / 80	81 / 77			78 / 74			86 / 81		
4260.647			47 / 45	72 / 68	66 / 63	69 / 65			74 / 70			86 / 81		
4271.934 . .			59 / 56	98 / 92	74 / 70	82 / 77			84 / 79					
Average			47 / 45	81 / 76	71 / 68	77 / 73			77 / 73			86 / 81		

NOTE. Other lines, among them 5569.77, 5573.05, and 5586.92, belong to this group.

TABLE I.—*Continued.*

LANTHANUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000	
	8	9
3921.695		21 / 21
3929.363	13 / 13	32 / 33
3949.199	26 / 26	24 / 24
3995.899	21 / 21	35 / 35
4031.865	7 / 7	14 / 14
4043.054	29 / 29	
4077.498	17 / 17	
4086.861	21 / 21	
Average	19 / 19	25 / 25

LEAD.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000			
	9	11	11¼	13½
3639.728				63 / 70
3683.622				70 / 76
4058.041	49 / 48	55 / 54	49 / 48	
Average	49 / 48	55 / 54	49 / 48	67 / 73

LITHIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000													
	2½	3	4	4½	5	5½	6	6½	7	8	9	9½	10	10¼
6708.2	[1]18 11	[1]24 14	[1]30 18				[1]66 40		[1]52 31					[1]130 78
3232.77 .... Principal series										53 66	74			
6103.77 .... 1st subordinate series	[1]38 25	[1]37 24		[1]56 37		[1]77 50		[1]116 76				[1]177 116		
4972.11..... 2d subordinate series										222 181				

[1] Eye observation.

MANGANESE.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000									
	4¾	6	7	10½	11	11¼	11½	12½	12¾	14
4018.269...		13 13	12 12					32 32	27 27	37 37
4026.583...	8 8				17 17					
4030.947...						19 19			33 33	34 34
4035.883...	8 8	18 18	13 13						26 26	32 32
4061.881...						20 20				
4235.298...	10 10		22 21							
4235.450...	8 8		18 17	27 25	37 34				32 20	36 33
4239.890..	13 12	21 20					31 29	48 45		47 44
4257.815...	14 13	21 20	22 21	25 23	39 36				47 43	47 43
4266.081...	14 13	20 19	22 21	38 35			40 37	41 38	40 37	46 43
4281.257...	10 9		21 20	37 34	43 40		39 36	41 38	38 35	44 41
4284.223...	12 11									
Average .	11 10	19 18	19 18	32 30	34 32	20 20	37 34	40 38	35 33	40 38

MAGNESIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
	7½	8	8½	9	10	11	13
2795.632			8 12	19 27			
2802.805			18 26	16 23			
[1]2852.239 No series	12 17	6 9			23 32	21 30	29 37
Average	12 17	6 9	13 19	18 25	23 32	21 30	29 37
3829.501				33 34	28 29		
3832.450				30 31	31 32		
3838.435 1st subordinate series				40 41	30 31		
Average				34 35	30 31		
5167.497				66 51			
5172.856				62 48			
5183.791 2d subordinate series				47 36			
Average				58 45			

[1] This line, much the strongest in the spectrum of magnesium, is nearly coincident with, and consequently almost always obscures a much weaker line of the first subordinate series.

MERCURY.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
			10	11			
3650.3			63 70	63 70			
5461.0			90 66				
Average			77 68	63 70			

TABLE I.—*Continued.*

MOLYBDENUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000			
	9		$11\frac{1}{2}$	
3132.749			31	40
3158.3			27	34
3170.5	28	33	32	40
3194.2	18	22	33	41
Average	23	28	31	39

NICKEL.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000					
	$9\frac{3}{4}$		$12\frac{1}{2}$		$14\frac{1}{2}$	
3391.180			14	17		
3413.637			19	23		
3414.092			19	23		
3437.447	20	23			34	39
3458.606			27	31	29	33
3461.322	16	18	23	25		
3500.993			24	27	35	40
3515.207			34	38	41	45
3524.677			30	35		
5155.937	24	18				
Average	20	20	24	26	35	39

TABLE I.—*Continued.*

NEODYMIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000: 9
4279.874	18 17
4281.0	7 7
4284.8	6 6
4302.7	7 7
4319.1	12 11
4334.3	5 5
4348.0	11 10
4362.2	5 5
4385.8	15 14
4401.0	14 13
4420.7	6 5
And many others	
Average	10 9

OSMIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000: 12¾	13
4260.993		17 16
4520.633	20 18	18 16
Average	20 18	18 16

PALLADIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000					
			12	13½		
3373.139				39 33		
3404.725				47 40		
3421.367			20 17	44 38		
3433.578				36 31		
3441.539				36 31		
3460.884			21 18	31 27		
3481.300			24 21	29 25		
3489.915			22 19	34 30		
3609.696			24 22	48 44		
3634.841				45 41		
3690.483			19 17	31 28		
Average			22 19	38 33		

PLATINUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000					
		12¼	12¾	13	14¼	
2830.41				22 16		
2893.98				20 14		
2897.99				17 12		
2929.91			10 12	24 17		
2998.079		20 15	23 17	25 18	18 13	
3042.745				25 18	31 23	
3064.824					21 16	
4442.723		23 25		28 31		
Average		21 20	20 15	23 18	24 18	

TABLE I.—*Continued.*

POTASSIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000					
			8	9		
4044.294			76 75	93 92		
4047.338			88 87	106 105		
Principal series						
Average			82 81	99 98		

RHODIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000						
		12	12¼	12¾	13	14½	
3399.839		17 20					
3412.417		23 27					
3435.039		16 19					
3462.184		19 21					
3474.920		20 23					
3479.053		22 25					
3502.674		21 24					
3507.466		26 29					
3626.744		16 18					
3658.135		15 17					
3666.366		23 25					
3690.853		27 29					
4211.304					45 43		
4374.981			31 28	38 34	45 41	37 34	
Average		20 23	31 28	38 34	45 42	37 34	

TABLE I. *Continued.*

RUBIDIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
			8	8½			
4201.98			73 70	123 117			
4215.72			75 71	88 84			
Average			74 71	106 101			

RUTHENIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
				12			
3429.689				29 34			
3499.095				26 30			
3593.178				21 23			
3599.914				27 30			
3625.339				32 36			
3635.084				20 22			
3637.612				25 28			
3661.525				33 36			
3663.520				17 19			
3669.688				23 25			
3678.456				20 22			
3727.073				25 27			
3728.173				21 23			
3730.577				33 36			
Average				25 28			

TABLE I.—*Continued.*

SCANDIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000					
			12			
4247.0			22 21			
4314.3			30 28			
4320.9			26 24			
Average			26 24			

SILICON.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
	8½	9	9½	10	11	11½	12
2506.994	13 21						
2516.210	12 19						
2519.297	18 28						
2524.206	13 21						
2528.599	22 34						
2881.695	20 28	21 29		25 35	31 40		
3905.660			31 32		44 45	40 41	39 40
Average	16 25	21 29	31 32	25 35	38 43	40 41	39 40

TABLE I.—*Continued.*

SILVER.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000						
		8	9¾	12½	13		
3280.80		29 34	28 33	32 39			
3383.00			34 40	27 32	32 38		
Average		29 34	31 37	30 36	32 38		

SODIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000							
	3	3½	6½	7	7½	8	8½	9	10½
3302.504						47 57	67 81		
3303.119						61 74	57 70		
D_2 5890.182	[1] 30 20		[1] 69 47	62 42				94 62	[1] 121 82
D_1 5896.154		[1] 25 17	[1] 63 43	78 53				122 83	[1] 116 79
Principal series Average	30 20	25 17	66 45	70 48		54 66	62 76	108 73	110 81
5682.861					314 221	[1] 400 280		426 300	
5688.434	[1] 100 70	[1] 130 91			368 259	[1] 345 242		460 323	
2d subordinate series Average	100 70	130 91			341 240	373 261		443 312	

[1] Eye observation.

TABLE I.—*Continued.*

STRONTIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000					
	8½	10	10½	11	11½	12
4077.885				26 / 26	39 / 38	
4215.703	28 / 27		34 / 32	34 / 32	45 / 43	
4742.07				42 / 36	37 / 31	
4784.43				42 / 35	35 / 29	
4812.01				23 / 19		29 / 24
4832.23				50 / 41	48 / 40	
4876.35				40 / 33	40 / 33	
5222.43			46 / 35			
5225.35			60 / 46			
5229.52			44 / 34			
5238.76			45 / 34			
5257.12			60 / 46			
Group A						
Average	28 / 27		48 / 38	37 / 32	41 / 36	29 / 24
3351.35			53 / 63			
3380.89			57 / 67			71 / 83
3464.58						78 / 89
4607.510	46 / 40	57 / 50		53 / 46		93 / 81
4962.45				90 / 72		83 / 66
Group B						
Average	46 / 40	57 / 50	55 / 65	72 / 59		81 / 80

TABLE I.—*Continued.*

TANTALUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000
	12
3918.6	13 / 13
3922.9	19 / 19
3931.1	11 / 11
3970.3	16 / 16
3982.1	18 / 18
3988.9	23 / 23
4003.9	14 / 14
4007.0	14 / 14
4027.1	18 / 18
4030.1	21 / 21
4061.6	15 / 15
4064.8	20 / 20
4105.2	18 / 18
Average	17 / 17

THALLIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000	
	$9\frac{1}{2}$	11
3519.342	49 / 56	[1]87 / 99
3520.58		[1]75 / 80
Average	49 / 56	81 / 93

[1] Good lines.

TABLE I.—*Continued.*

TUNGSTEN.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000			
	9½		11	
4009.0	20	20	13	13
4074.7			15	15
Average	20	20	14	14

TIN.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000									
	9¼		10		12½		13		14½	
2706.61			30	20						
2812.70			57	40						
2840.06			34	24						
2850.72			34	24						
2863.41			35	25						
3009.24			41	31						
3032.88			30	22						
3034.21			48	36						
3175.12					59	48			68	54
3262.44	46	37			58	47	55	44	63	51
3330.71					55	44			77	64
Average	46	37	39	28	58	48	55	44	69	58

TITANIUM.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000											
	8		8½		9		10½		11		11½	
3186.564	25	20										
3192.120	27	22	26	21								
3200.034	22	18	31	25								
3222.970	19	15										
3234.635	15	12									26	21
3236.703	16	13									22	18
3239.170	16	13									27	22
3242.125	15	12									18	15
3254.314			21	17								
3326.907			17	14								
3341.967	18	15	18	15							23	19
3349.043							17	14			20	17
3361.327			8	7			16	14				
3372.901			10	9			18	15				
3380.397			19	16								
3900.681			17	17								
3904.926			15	15								
3913.609			15	15								
3924.673			13	13								
3930.022			9	9								
3947.918			10	10								
3948.818			9	9	19	19						
3956.476			11	11	13	13					18	18
3958.355					16	16						
3981.917					18	18						
3989.912					15	15					16	16
3998.790									15	15	22	22
4009.079			13	13								
4024.726			15	15								
Average	19	16	15	14	16	16	17	14	15	15	21	19

THORIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000						
			8	9			
4248.1			12 11	15 14			
4283.7			14 13				
4381.6			7 7				
4391.3			9 8	8 7			
4433.2			14 13	11 10			
4439.3			15 14				
4441.1			15 14	20 18			
4465.5			21 19	12 11			
4487.7			4 4				
4510.7			21 19				
Average			13 12	13 12			

YTTRIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000								
		4¾	6	7	10	11	12½	13	
3950.497		5 5	7 7			15 15	17 17	14 14	
3982.742		4 4		4 4			17 17	18 18	
4309.780					11 10				
4358.892					17 16				
4375.110					21 19				
4398.185					23 21				
4422.760					20 18				
Average		5 5	7 7	4 4	18 17	15 15	17 17	16 16	

NOTE.— Several other yttrium lines were measured, and found to agree well with the above.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000: 8 (observed)	8 (reduced)	10 (observed)	10 (reduced)
3902.399	5	5		
3910.984	9	9	13	13
3913.0	14	14	17	17
3914.5			23	24
3922.560	13	13		
3924.8	22	22		
3925.4	12	12	18	18
3928.1	14	14		
3934.2	5	5		
3937.7	18	18	19	19
3938.3			20	20
3939.5	26	26	23	23
3950.4			15	15
3979.6	17	17	17	17
3984.5	16	16	15	15
3984.7	21	21	24	24
3989.0	12	12	22	22
3990.712	22	22		
3992.971	15	15		
3998.9	14	14		
4042.8	17	17		
4051.204	16	16		
4051.491	19	19		
4057.2	24	24		
4092.821	10	10		
4105.318	23	23		
4120.6	17	17		
4123.539	18	17		
4128.251	19	18		
4132.100	13	13		
4134.589	22	21		
Average	16	16	19	19

TABLE I.—*Continued.*

URANIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000						
			9½	11	12		
3886.4					12 12		
3993.6			4 4	3 3			
3912.7				5 5			
3916.0				4 4			
3932.2			7 7	11 11	14 14		
3951.5				7 7			
3954.9				6 6			
3982.6				4 4			
3986.0				5 5			
3987.6				13 13			
3989.7				12 12			
4050.3				10 10			
4064.6				13 13			
Average			6 6	8 8	13 13		

ZIRCONIUM.

Wave-length λ	Pressure in atmospheres, followed by Δλ observed and Δλ reduced to λ 4000						
			9				
3958.355			13 13				
3999.117			24 24				
4029.796			23 23				
Average			20 20				

TABLE I.—*Continued.*

ZINC.

Wave-length λ	Pressure in atmospheres, followed by $\Delta\lambda$ observed and $\Delta\lambda$ reduced to λ 4000					
	7	8	9¾	11½	12¼	13½
3075.99	12 16					
3302.67		30 36		31 37		
3345.13		26 30		32 38		
3346.04 No series		30 36				
Average	12 16	29 34		32 38		
3282.42		27 33		32 39		
3303.03		22 27		37 44		
3345.62 1st subordinate series		25 30		33 39		
Average		25 30		34 41		
3018.50		46 62				
3035.93		44 58				
3072.10		49 64				
4680.317		61 52	68 58	60 51		
4722.341		51 43	62 52	77 63	58 49	63 53
4810.724 2d subordinate series		56 47		68 57	67 56	74 62
Average		51 54	65 55	68 57	63 53	60 58

RELATIONS OF THE SHIFTS TO EACH OTHER AND TO CERTAIN PROPERTIES OF THE ELEMENTS.

As already stated, at least many elements produce lines whose shifts for the same wave-length are quite different, but this difference is by no means a haphazard one. Thus any series (as described by Kayser and Runge) of lines produced by an element gives shifts which, when reduced to the same wave-length, are approximately equal, while the shifts of the series, principal, first and second subordinate, are to each other respectively very nearly as 1 : 2 : 4. As is well known, the lines of any series of a given element are quite similar in general appearance, but very different from those of other series; and the same is true of the several groups of lines, of iron and of copper, for instance, which have such different shifts. In general, then, it appears that lines of the same character of any element, when reduced to the same wave-length, give equal shifts, which, nevertheless, may differ widely from those of a different character, though of the same element.

Lines of the same series, not only of a given element, but also those of different elements, resemble each other closely, and consequently in comparing shifts of lines with other properties of the elements, it is neccessary to confine one's attention, as far as possible, to lines of the same character; and in accordance with this notion the following relations have to do with the shifts of what might be termed the most characteristic lines of the elements, that is, those lines which are the easiest to obtain (at least in the arc spectra) and which produce the sharpest reversals and consequently admit of the most accurate measurements.

On forming, for various elements, the product of the cube root of the atomic volume (*i. e.*, quotient of atomic weight divided by density) and the coefficient of linear expansion of the substance in the solid form, certain numbers are obtained whose ratios are approximately those of the shifts of the lines of the respective elements. This is shown in Table II, in which the atomic volume and coefficient of expansion both refer to 40° C.

TABLE II.

Element	Atomic weight W	$\sqrt[3]{W}$	Atomic volume V	Coefficient of linear expansion α	Temperature of melting point T	$\frac{48600}{T}$	Shift S	$\alpha \sqrt[3]{V}$
				.0000				
Al	27.11	3.00	10.6	2313	1123	43.3	55	50.6
Sb	120.43	4.94	17.9	1692 0882	710	68	49	43 23
As	75.01	4.22	13.2	0559	>773	<63	39	13
Ba	137.43	5.16	36.5	?	748	65	58 34	?
Be	9.08	2.09	4.9	?	>1270	<39	36	?
Bi	208.11	5.93	21.1	1621	538	90.3	49	44.7
B	10.95	2.22	4	?	?	?	49	?
Cd	111.95	4.82	12.9	3069	593	82	76	75.6
Cs	132.89	5.10	70.6	?	?	?	161	?
Ca	40.07	3.42	25.4	?	>Sr	<Sr	54 27	?
C	12.01	2.29	3.6	0786 0540 0118	?	?	50 0	?
Ce	140.20	5.20	21	?	>1273	<38	27	?
Cr	52.14	3.74	7.7	?	?	?	26	?
Co	58.93	3.89	6.9	1236	2070	24	24	23.6
Cb	93.73	4.54	13.0	?	?	?	33	?
Cu	63.60	3.99	7.1	1678	1330	36.5	33	32.5
E	166.32	5.51	?	?	?	?	47	?
Ge	72.48	4.17	13.2	?	?	?	44	?
Au	197.23	5.82	10.1	1443	1310	37	40	67
In	113.85	4.85	15.3	4170	449	108.3	88	103.5
Fe	56.02	3.83	7.2	1210	2080	23.3	25	23.3
La	138.64	5.18	22.5	?	>710	<69	32	?
Pb	206.92	5.92	18.1	29.24	605	80.3	60	76.9
Li	7.03	1.92	12.9	?	453	107	85	?
Mg	24.28	2.90	13.9	2694	1023	47	62 44	65
Mn	54.99	3.80	6.9	?	2170	22.9	33	?
Hg	200.00	5.85	14.1	6000	233	209	81	145
Mo	95.99	4.58	11.1	?	?	?	40	?
Ndi	140.80	5.20	?	?	?	?	11	?
Ni	58.69	3.89	6.7	1270	1870	26.5	28	24
Os	190.99	5.76	8.5	0657	2770	17.5	17	13.4
Pd	106.36	4.74	9.2	1176	1775	27.4	27	24.7
Pt	194.89	5.80	9.1	0899	2050	23.7	20	18.5
K	39.11	3.39	45.4	8415	335	145	132	300
Rh	103.01	4.69	8.6	0850	2270	21.4	25	17.4
Rb	85.43	4.40	56.1	?	311	156	132	?
Ru	101.68	4.67	8.4	0963	2070	23.5	28	20
Sc	44.12	3.53	17 (?)	?	?	?	24	?
Si	28.40	3.05	11.4	0763	?	?	43	17
Ag	107.92	4.76	10.2	1921	1230	39.5	39	42.2
Na	23.05	2.85	23.7	7105	369	132	108	204
Sr	87.61	4.44	34.9	?	>Ba	<Ba	70 35	?
Ta	182.84	5.68	16.9	?	?	?	17	?
Tl	204.15	5.89	17.2	3021	563	86.3	102	78
Th	232.03	6.15	20.9	?	?	?	18	?
Sn	119.05	4.92	16.3	2234	503	96.6	55	50.6
Ti	48.15	3.64	13 (?)	?	?	?	22	?
W	184.83	5.70	9.6	?	?	?	10	?
U	239.59	6.21	12.6	?	?	?	11	?
V	51.38	3.72	9.3	?	?	?	25	?
Y	89.02	4.47	?	?	?	?	15	?
Zn	65.41	4.03	9.1	2918	676	71.9	57	61.2
Zr	90.40	4.49	21.7	?	?	?	28	?

and the shift to a pressure of twelve atmospheres and wave-length 4000.

A similar expression is used by Raoul Pictet in his formula for deducing the melting points of the metals. He finds that the continued product of the absolute melting point, the coefficient of linear expansion of the substance in the solid state and the cube root of the atomic volume is nearly the same for all metallic elements except antimony and bismuth. Table II also shows the relation between Pictet's results and the shifts of the lines by giving the quotients obtained by dividing a constant, namely 48600, by the absolute melting points of the elements. The number 48600 was chosen to reduce his results to numbers comparable with the shifts at twelve atmospheres, that of iron being made to coincide with the value given by the product of its coefficient of linear expansion by the cube root of its atomic volume. It appears that the shifts are about as near the calculated values as are the melting points, and consequently in most cases the product of the shift by the absolute melting point is nearly constant; or what amounts to the same thing, the shift is inversely proportional to the absolute temperature of the melting point.

DESCRIPTION OF TABLE II.

The first column gives the symbols of those elements some of whose lines have been examined. Under W are their atomic weights, and in the next column, marked $\sqrt[3]{W}$ the cube roots of these weights. Under V are the atomic volumes at 40° C. and under α the coefficients of linear expansion at the same temperature. The column marked T gives the absolute temperatures of the melting points, and that marked $\frac{48600}{T}$ the quotients indicated. Under S are the shifts at twelve atmospheres and wave-length 4000, and the last column, marked $\alpha\sqrt[3]{V}$, gives the product of the coefficient of linear expansion and cube root of atomic volume multiplied by 10^6. The atomic weights are based on the assumption that the atomic weight of oxygen is 16, and are taken from a special Smithsonian publication (*Constants of Nature*, Part

V, Clark) for 1897. The atomic volumes and melting points are taken from Nernst's *Theoretical Chemistry*, and the coefficients of expansion from the *Physikalish-Chem. Tabellen von Landolt una Börnstein.*

In a few cases, more recent and possibly more accurate values of the above constants have been obtained, but the differences are not sufficient to materially affect the calculated shifts.

Like many other properties of the elements, the shift of their spectral lines is a periodic function of atomic weight, as is evident from the line of shifts as plotted in Plate XVIII, in which the abscissæ are atomic weights and the ordinates the shifts per atmosphere of the lines of the given elements. The maxima fall, as do those of atomic volume, on the alkali metals, lithium, sodium, potassium, rubidium, and cæsium. In the case of those elements that have two or more groups of lines of different shifts, the group giving the best lines was always the one selected. Thus for the alkalies the lines selected are those of the principal series, which are by far the best lines for measurement of these elements, and besides, by selecting lines of the same series, it is possible to compare the shifts of the lines of the alkali metals, all of which belong to the same family of elements, or Mendelejeff group. For similar reasons lines of the second subordinate series were selected in the case of zinc, cadmium, and mercury. For calcium the *g* group of lines was selected, and the corresponding groups for strontium and barium. A different selection of lines where possible would not alter the periodic nature of the curve, but simply increase or decrease the values of the maxima and minima.

As shown by the results tabulated in Table II, those elements, such as sodium, potassium, indium, thallium, cadmium, and others, which have very large coefficients of linear expansion, have also very large shifts, and the converse is equally true.

Another and rather simple relation is this: The shifts of the spectral lines of similar elements, in the main those of the right or left half, as commonly tabulated, of a Mendelejeff group, are

PLATE XVIII.

PRESSURE SHIFTS OF SPECTRAL LINES AS A PERIODIC FUNCTION OF ATOMIC WEIGHT.

generally proportional to the cube roots of the atomic weights of the elements that produce them. This is shown in Table III, in which it will be seen that the observed and calculated values agree quite closely except in very few cases. The single carbon line shifts about twice the calculated amount, and the lines of a few other elements—platinum, osmium, yttrium, thorium, tantalum, and tungsten—only about half as much as would be expected. It is just possible that in these cases lines comparable to those measured of the other elements have not been selected. The lines measured of neodymium and uranium shift much less than the calculated amounts. Whether this is true of all the numerous lines of these two elements I am unable to state.

DESCRIPTION OF TABLE III.

Each horizontal row of Table III contains first the symbol of a certain element, followed by the observed shifts of its lines in thousandths of an Ångström unit for twelve atmospheres and wave-length 4000; then the symbol of an element of the same group followed by the calculated shift of its lines, and finally the observed shift of the same lines. The shifts marked *standard* are assumed to be correct, and each marked *calculated* deduced from the standard of the same horizontal row on the assumption that they are to each other as the cube roots of the atomic weights of the respective elements.

In determining the groups of similar elements I have been guided in some measure by their spectra, and since the grouping adopted is not exactly, though very nearly, that which is commonly made, I have thought it necessary to give it in Table IV. It will be seen that sodium, for instance, is classed with lithium, potassium, rubidium, and cæsium, which it strongly resembles spectroscopically, rather than, as is often done, with copper, silver, and gold, which it does not resemble in this respect. Again, and for similar reasons, magnesium is classed with calcium, strontium, and barium, rather than with zinc, cadmium, and mercury. In no case, however, is there a change of an element

TABLE III.

Showing shifts in thousandths of an Ångström unit for twelve atmospheres and wave-length 4000.

Standard		Calculated		Observed
Cs	161	Li	60	85
Cs	161	Na	90	108
Cs	161	K	109	132
Cs	161	Rb	139	132
Cu	33	Ag	39	39
Cu	33	Au	48	40
Ca	54 27	Mg	46 23	44 30
Ca	54 27	Sr	70 35	65 37
Ca	54 27	Ba	81 40	58 34
Zn	57	Be	30	36
Zn	57	Cd	68	76
Zn	57	Hg	83	81
La	32	Y	28	15
La	32	Sc	22	24
Al	55	B	40	49
Al	55	In	89	88
Al	55	Tl	106	102
Ti	22	Zr	26	28
Ti	22	Ce	30	27
Ti	22	Th	35	18
Sn	55	C	26	50
Sn	55	Si	34	43
Sn	55	Ge	47	44
Sn	55	Pb	66	60
V	25	Cb	28	34
V	25	Nd	35	11
V	25	Ta	38	17
Bi	49	As	35	38
Bi	49	Sb	41	49
Bi	49	E	45	47
Cr	26	Mo	32	40
Cr	26	W	40	19
Cr	26	U	43	9
Fe	25	Ru	36	28
Fe	25	Os	38	17
Ni	28	Pd	34	27
Ni	28	Pt	42	20
Co	24	Rh	29	25

from one to another of the Mendelejeff groups, and besides the right and left halves, as usually tabulated, are in the main retained, the only changes being in the case of elements of small atomic weights, which have many properties in common with the

elements of each half of their several groups, and which are often regarded as common to the two halves. Thus, as just stated, magnesium is placed with calcium, strontium, and barium, because spectroscopically it resembles them rather than zinc, cadmium, and mercury, though it has so many properties in common on the one hand with those of calcium, strontium, and barium, and on the other with those of zinc, cadmium, and mercury, that it might very well be classed with either group.

TABLE IV.

Showing the adopted grouping of similar elements.

Group I		Group II		Group III		Group IV		Group V		Group VI	Group VIII		
Li	Cu	Mg	Be	Sc	B	Ti	C	V	As	Cr	Fe	Ni	Co
Na	Ag	Ca	Zn	Y	Al	Zr	Si	Cb	Sb	Mo	Ru	Pd	Rh
K	Au	Sr	Cd	La	Ga	Ce	Ge	Ndi	E	W	Os	Pt	Ir
Rb		Ba	Hg		In	Th	Sn	Ta	Bi	U			
Cs					Tl		Pb						

SUMMARY OF RESULTS.

The following list of relations between the shifts of spectral lines, the conditions under which they are produced and the properties of the elements producing them is probably quite imperfect; some of them may be more or less accidental, and in all probability others quite as important have been overlooked. However, I have not searched at all carefully for such relations, and the present list contains only those which presented themselves from time to time during the investigation, and which I trust may be of service to anyone who attempts an explanation of the observed phenomena.

These relations are:

1. Increase of pressure causes all isolated lines to shift towards the red end of the spectrum.

2. This shift is directly proportional to the increase of pressure.

3. It does not depend upon the partial pressure of the gas or vapor producing the lines, but upon the total pressure.

4. The shift of the lines seems to be nearly or quite independent of temperature.

5. The lines of bands (at least of certain "cyanogen" and aluminium oxide bands) are not appreciably shifted.

6. The shifts of similar lines of a given element are proportional to the wave-lengths of the lines themselves.

7. Different series of lines (as described by Kayser and Runge) of a given element are shifted to different extents. When reduced to the same wave-length these shifts are to each other approximately as 1 : 2 : 4, respectively, for the principal, first and second subordinate series.

8. Similar lines of an element, though not belonging to a recognized series, are shifted equally (when reduced to the same wave-length), but to a different extent than are those unlike them.

9. Shifts of similar lines of different substances are to each other, in most cases, inversely as the absolute temperatures of the melting points of the elements that produce them.

10. The shifts of similar lines of different elements are to each other approximately as the products of the coefficients of linear expansion and cube roots of the atomic volumes of the respective elements (in the solid state) to which they are due.

11. Analogous or similar lines of elements belonging to the same half of a Mendelejeff group shift proportionately to the cube roots of their respective atomic weights.

12. The lines of those substances which, in the solid form, have the greatest coefficients of linear expansion have the greatest shifts. The converse is also true.

13. The shift of similar lines is a periodic function of atomic weight, and consequently may be compared with any other property of the elements which itself is a periodic function of their atomic weights.

The results of this investigation can be fairly well expressed by the simple equation.

$$\Delta\lambda = \alpha\beta\lambda(p - p_0)$$

when $\Delta\lambda$ is the increase of wave-length λ of any given line produced by the increase of pressure $p - p_0$, β a constant for any

series of lines and α a constant for any element. That is β for any series of a given element is the same as β for the corresponding series of any other element, while α for any series of a given element is the same as for α for any other series of the same element. If we write β_0 for the principal series, β_1 for the first subordinate and β_2 for the second subordinate, then, approximately, $\beta_0 : \beta_1 : \beta_2 = 1 : 2 : 4$.

By suitably choosing β, α may be replaced in most cases by $\frac{1}{T}$, where T is the absolute temperature of the melting point, or again by $\epsilon \sqrt[3]{V}$ where ϵ is the coefficient of linear expansion of the substance in the solid state and V the atomic volume (the objection to these expressions comes from the fact that for many elements neither T nor ϵ is known); or finally, for either half of any Mendelejeff group, by $\sqrt[3]{W}$, where W is the atomic weight. From this last expression it is evident that α, and therefore $\Delta\lambda$, is a periodic function of atomic weight.

The observations upon which the above conclusions are based, though very numerous, are by no means as complete as could be desired, and I feel quite sure that a more searching examination of a larger number of lines, probably at considerably increased pressures, would add materially to our knowledge of the interesting relations between the spectral lines and the conditions under which they are produced.

DISCUSSION OF THE RESULTS.

How to interpret the shifts of the lines, their relations to each other and to other properties of the elements that produce them is not very evident. However, on any theory of the emission of waves the wave-length increases with increase of the linear dimensions of the segment or portion of matter producing them. Consider therefore an isolated body, to be definite a rectangular bar of steel say, producing vibrations. Waves of different lengths may be given off simultaneously, but the length of each will be proportional to the length of the segment producing it. If the linear dimensions of the bar be increased, the other properties

remaining unchanged, the wave-length of each set of vibrations will be correspondingly increased, the total increase in each case being proportional to the wave-length itself. Now suppose the bar in the midst of a great number of others of either the same or of different material and all moving at random with considerable velocity. Many collisions will take place; part of the energy of the system becoming internal energy of the bar in question and thereby increasing its linear dimensions and consequently the wave-lengths of its vibrations. Further, the more numerous the bars in a given space the more frequent in the same proportion will be the collisions and therefore the greater will become the internal energy of the bar, its linear dimensions and the wave-lengths of its vibrations. Again, of two bars under the supposed conditions, that one which has the greater coefficient of linear expansion will suffer the greater change in the lengths of its waves.

Since, at any given temperature, the coefficient of expansion of a bar of metal remains constant, so far as is known, no matter how small the bar, and since also the coefficient of expansion of a porous bar, or one bored to any extent and in any direction, is the same as that of a solid bar of the same substance, it would seem on pushing these ideas to the limit, that the coefficient of expansion of a substance in the solid form is also more or less nearly a measure of the expansion of its smallest parts or molecules. Nor does it seem unreasonable to suppose, when these molecules are moving rapidly and in the midst of many others, as they are when the substance is in the form of a gas, that their collisions would lead to an increase of the internal energy of the molecules themselves and consequently to their expansion and to an increase in the wave-lengths of their vibrations. At any rate if the particles producing light-vibrations have properties like those of appreciable masses of the same substance, then the above considerations in regard to the steel bar offer a possible explanation of many, and probably the most important, of the observed facts in regard to the shifts of the spectral lines. In this way is explained why the wave-lengths should always increase with

increase of pressure, and why it is independent of the partial pressure of the gas to which the lines are due. It is also evident that the shifts of the lines should be proportional to their wave-lengths, and greatest for those substances which have the greatest coefficient of linear expansion. This idea offers at least a partial explanation as to why the shifts of the lines should be, as experiment shows them, practically independent of temperature when the pressure is kept constant, since in this case the greater velocity of the particles due to increase of temperature is offset in a measure by the corresponding rarefaction, so that the increase of internal energy of the molecules *due to collisions* may be but slightly, if at all, changed by change of temperature alone. Still an increase of the temperature alone almost certainly increases the amplitudes of the vibrations—the lines become more intense—and it is difficult to see why the internal energy of the molecule should not at the same time be so increased as to make its linear dimensions greater. This, however, it seems would make the wave-lengths greater, a result that is not in accord with experiment.

Why different series of lines of the same element should shift differently is far from evident, and it is with the greatest hesitation that I offer the slightest suggestion in regard to it.

Conceivably the vibrating particles may expand differently in different directions, or possibly the different series of lines may be due to entirely different molecular complexes of very different coefficients of expansion. This latter idea seems to be supported in a measure by the following considerations: The melting point of a substance and its coefficient of expansion both appear to be in some sense inversely proportional to the ability of its particles to resist external influences; and those molecular complexes least capable of resisting external influences may, therefore, at the temperature of the electric arc, be subject to dissociation and possibly to other changes as well. Now it happens that those substances which furnish clearly marked series of lines, as do sodium, potassium, cadmium, mercury, and others, are those whose melting points are among the lowest and

whose coefficients of expansion are the greatest. Should dissociation take place, it is clear that the dissociated parts must be either less subject to external influences or else less powerfully acted upon than are the undissociated parts, else they too would still further dissociate, which process evidently stops somewhere. In either case a smaller coefficient of expansion of the parts might be expected than is that of the undissociated portions. Again it seems but natural to suppose the dissociation taking place along planes of symmetry, should such planes exist, or at least in a manner that would leave the parts with linear dimension approximately but half those of the original whole. Supposing, then, the coefficients of expansion, or better possibly, the amounts of energy used in producing expansion of the parts to be such as to cause these coefficients to be to each other as the linear dimensions of the particles themselves, we have at once an explanation of the 1 : 2 : 4 relation of the shifts of the series.

This also suggests a possible explanation of the fact that analogous elements, as rubidium and cæsium, tin and lead, and others give lines that shift proportionately to the cube roots of their atomic weights, since (if the atoms are of about the same density) the cube roots of their weights are to each other as their linear dimensions. Or, on the other hand, if, as seems possible, the shifts of the lines are to each other as the linear dimensions of the particles to which they are due, it follows that analogous elements — elements of the same half of a Mendelejeff group — differ from each other in the main because of the difference in the linear dimensions of their atoms.

Again I wish to say that these suggestions are offered with the greatest hesitation (the assumptions made are not yet justified), and only with the hope that they may be of some service in mapping out further investigations along this line of spectrum analysis.

HISTORY OF THE PRESENT INVESTIGATION.

The present investigation was begun in February 1895 by Dr. J. F. Mohler and myself, and continued as joint work till

December of the same year. Our accumulated results on twenty-three elements were then published in the ASTROPHYSICAL JOURNAL, December 1895, and likewise, though in a much less complete form, in the Johns Hopkins University *Circulars* for February 1896. A preliminary account of it had also been given by Dr. Mohler at the Springfield (1895) meeting of the American Association for the Advancement of Science.

Dr. Mohler then examined alone the effect of very low pressures on a few of the elements whose behavior at high pressure was already known, and published his results in the ASTROPHYSICAL JOURNAL of October 1896, and I, working independently, extended the examination at high pressures to a number of additional elements, the results of which appeared in the November 1896 number of the same JOURNAL.

The present paper, though including all that has been done in this line, except Mohler's work at low pressure, contains much that is new — the history, so far as there is one, of the subject; the behavior of several additional elements (the metallic elements are now practically exhausted); the behavior of different groups of analogous lines, like those of copper and iron, and in particular the different series of lines as furnished by lithium, sodium, zinc, and others; and also a fuller study of several of the elements, iron, zinc, copper, cadmium, among others previously studied by Mohler and myself.

DESCRIPTION OF PLATE XVII.

Some idea of the effect of pressure on spectral lines may be got from the accompanying plate, which is taken from a few of the negatives obtained during the course of my work. I shows the pair of sodium lines λ 3302.504 and λ 3303.119. The inner portion was taken at a pressure of eight and one-half atmospheres and the outer portion at one atmosphere. On the outside the unsymmetrical nature of these lines is clearly seen, the spreading being to the violet; yet, as shown by the plate, the lines under pressure are greatly shifted towards the red of the spectrum. II is from the New Concord meteorite, the inner portion being

taken at a pressure of twelve atmospheres. This shows several of the iron lines that shift to a greater extent than do others of the same element. It shows also a portion of a cyanogen band, whose lines are not appreciably displaced. Further, it shows that the lines under pressure reverse more readily than do the same lines at normal pressure. III. the inner portion of which was formed at a pressure of seven atmospheres, shows the great difference in the shifts of two classes of copper lines. In this case the plate was taken from an arc formed between a copper and a brass rod, the brass forming the lower and positive pole. IV shows the potassium lines λ 4044.294 and λ 4047.338, which are greatly shifted. The small line between them is due to iron. The pressures were for the outsides and the middle, one and eight and a half atmospheres respectively. V gives the rubidium lines (in the cyanogen band), the shifts of which are very evident. In this case the pressures were also eight and a half and one atmospheres. In fact, V and IV are but different portions of the same plate.

In closing I wish to thank Professor Rowland and Dr. Ames, under whose direction this work was conducted, not only for their assistance every time it was needed, but also for the thoroughly kind and helpful manner in which it was invariably given.

My thanks are also due to Mr. L. E. Jewell for the willingness with which he often brought his extensive knowledge of the spectra of the elements to my aid.

THE NEW SERIES IN THE SPECTRUM OF HYDROGEN.

By J. R. Rydberg.

In the April number of this Journal, page 243, Professor Kayser expresses the opinion that Professor Pickering is wrong in representing the newly discovered hydrogen series in the spectrum of ζ Puppis by the same formula as the old one.

Although I can subscribe without hesitation to the opinion of Professor Kayser as to the relation of the two series, yet the reasons he adduces to confirm his conclusion do not seem quite sufficient. If it should turn out to be a fact that the two series can be united into a single one, then, indeed, strong arguments must be advanced to dispute the correctness of such an arrangement.

The first condition to be fulfilled, before we draw any conclusion from the analogy with other spectra, is to obtain a rigorous proof that the two series have a common limit. For this purpose I have calculated the two series independently of each other, after reducing the wave-numbers to vacuum.

The formula of Balmer for the old series becomes then with Professor Rowland's values

$$n = 27418.75 - \frac{109675.00}{m^2}$$

where n is the wave-number and m the series-number of a line; and my general approximate formula

$$n = n_0 - \frac{109675.00}{(m+\mu)^2}$$

gives for the new series, using the most complete of the observed series for ζ Puppis,

$$n = 27418.79 - \frac{109675.00}{(m+0.500737)^2}.$$

The corresponding values in air (16°, 760^{mm}) are:

m	5	6	7	8	9	10
λ obs.	4201.6	4026.5	3924.9	3858.6	3817.2	3783.4
λ calc.	4201.54	4027.31	3925.18	3859.76	3815.17	3783.35
diff.	+0.06	−0.81	−0.28	−1.16	+2.03	+0.05

Thus the limit n_0 coincides exactly in the two series, and we evidently obtain the formula of Professor Pickering by inserting in place of 0.500737 the approximate value 0.5, and then substituting $\frac{1}{2}m$ for m.

From this we see first of all that the condition for the correspondence of the series, as nebulous and sharp series of hydrogen, are fulfilled as exactly as possible, if we consider their different intensity and sharpness, as pointed out by Professor Kayser. Consequently we are perfectly justified in comparing these series with those known in other spectra. Secondly, we find that the formula of Professor Pickering contains the two given here and differs from them only by giving other numbers to the lines and representing the two series as one.

Which of these two methods is to be considered the correct one can easily be decided by reference to the existing analogy with other spectra, seeing that we have for some elements hitherto examined the following values of the constant μ:

Element	Nebulous series	Sharp series
H	1.000000	0.500737
Pa	0.997273	0.858110
He	0.996084	0.701464
Li	0.998063	0.597337
Na	0.988436	0.649840
Zn	0.905336	0.269148
Cd	0.906478	0.327899
Ag	0.982165	0.447358
Cu	0.975792	0.399765

If the two series were related in the way indicated by the formula of Professor Pickering, the values of μ for the same element ought to differ by a quantity approaching 0.5, so that the terms of one series would fall half-way between the terms of the other. But, as we see from the table, these differences vary in an irregular manner. Therefore hydrogen would be the only known element by which the two series could be thus united in one formula. It is worthy of notice that the formula of Kayser and Runge

$$n = A - Bm^{-2} - Cm^{-4}$$

does not permit a comparison of this kind between the series.

Another argument, not yet mentioned, against the combination of the two series, which would be sufficient to decide the question, can be derived from the analogy with other spectra. For, as I have shown explicitly,[1] the constituents of the doublets and triplets of the nebulous series are built up after exact rules, and form new doublets and triplets of a higher order, while the constituents of the sharp series, so far as we know, are simple lines. Evidently it would be absurd to unite these two kinds of lines in one series, where the terms would be alternately simple and alternately double and triple, as would be a necessary consequence if we should follow the analogy given by the formula of Professor Pickering.

We arrive, therefore, at the definitive conclusion that *the two series of hydrogen are to be represented by two distinct formulæ*, even if it may be possible to unite them with great approximation in a single equation.

Hitherto the spectrum of hydrogen has appeared through its simplicity to differ from all others, and I have also adduced this circumstance among the many which give to hydrogen a quite peculiar place in the system of elements. Through the discovery of the new series the analogy between this spectrum and the others is evident; but there remains still the exceptional simplicity in the values 1 and ½ for the constants μ of the nebulous and of the sharp series. However, as the analogy ought to hold good in all details, we are compelled to adopt the assumption that the lines of hydrogen are double, just as are those of other elements. In this connection we may recall an observation made by Professor Michelson in his researches on close doublets by the interference method, from which he found that *Ha* actually has two components of nearly the same intensity, quite as we should expect from the monatomicity of hydrogen. Now, if this be the case, it is evident that the formula of Balmer will lose its quality, hitherto unparalleled in

[1] *Wied. Ann.*, **50**, 629, 1893.

science, to represent with absolute exactness a series of quantities given by nature. The formula is to be divided into two, with different values for the limit n_0, but with the same value for the constant μ, which very likely will differ a little from the exact values 0 or 1.

At all events we can now, without any risk of mistake, venture to compute the second part of the sharp series of hydrogen, the so-called *principal series*. Then, as I have pointed out already in my general exposition of the constitution of line spectra[1] and have afterwards tried further to confirm,[2] there can be no doubt that these series are really parts of a single group of lines with two variable integral parameters, the general formula of which can be written approximately[3]

$$\frac{n}{109675.00} = \frac{1}{(m_1+\mu_1)^2} - \frac{1}{(m_2+\mu_2)^2},$$

m_1 and m_2 being the parameters, and μ_1 and μ_2 constants. In the present case the formula becomes

$$\frac{n}{109675.00} = \frac{1}{(m_1+1)^2} - \frac{1}{(m_2+0.5)^2},$$

where for the sharp series m_1 is always unity, and m_2 is variable and can assume the values 1, 2, 3, 4, ... ; for the principal series, on the contrary, $m_2 = 1$, while m_1 varies. By giving m_1 or m_2 the constant values 2, 3, 4, ... and then varying m_2 or m_1 respectively, other series are formed. Negative values of n have the same meaning as positive ones.

On computing from the above formula the values of n for the principal series we find the following lines:

m_1	1	2	3	4	5
n	21325.69	36558.33	41889.75	44357.44	45697.91
λ	4687.88	2734.55	2386.50	2253.74	2187.60

[1] "Recherches sur la constitution des spectres d'émission," etc. *K. Svenska Vetensk. Akad. Handl.*, **23**, No. 11, 1889.

[2] This JOURNAL, **4**, 91, 1896.

[3] "Recherches," etc., p. 64. This law is also given explicitly in the abstracts of the memoir in *Zeit. Phy. Chem.*, *C. R.*, and *Phil. Mag.* for 1890, so that it seems impossible for Professor Schuster to base his claim to a second discovery on the law not having been sufficiently published.

The values of n are calculated for vacuum, but the values of λ are reduced to air ($16°$, 760^{mm}) in order to correspond to the observed values.

A glance at the above numbers shows at once that only the first line is likely to be found in star spectra, as all the others are situated in the region cut out by the absorption of the atmosphere. This line, which would correspond to the red line of Li ($\lambda = 6708.2$) and to the two D lines of Na, ought to possess an extraordinary intensity, exceeding by far that of all the other lines of hydrogen in the visible spectrum.

These conclusions are confirmed in every respect, if we consider the spectra of stars of the fifth type. In the *Annals of the Harvard College Observatory*, 28, Part 1, p. 48 ("Spectra of Bright Stars," by Antonia C. Maury and E. C. Pickering) we find in Table III, in the column under "Curve," the following lines with their intensities:

	λ	i		λ	i
H [D_1 7]	3889	1	H [S_1 5]	4200	3
H [S_1 7]	3926	1	H [D_1 4]	4340	3
H [D_1 6]	3970	1	H [S_1 4]	4544	2
H [S_1 6]	4026	1	....	4614	2
....	4059	4	H [S_1 1]	4688	10
H [D_1 5]	4102	5	H [D_1 3]	4862	1

The designations in the first column correspond to the system introduced for other spectra.[1] D is a line of a nebulous (diffuse) series, S a line of a sharp series, the numbers give the values of m.

As we see, *all the known lines of hydrogen are surpassed in intensity by the line 4688, which corresponds almost exactly to the computed value 4687.88 and which we can, with full certainty, indicate as the first line of the hydrogen spectrum, being at once the first term of the principal and of the sharp series.*[2]

Of the remaining lines in the spectrum of hydrogen H [S_1 3]

[1] "Recherches," chap. v, p. 76.

[2] There is a line at λ 4687 in the spectra of several nebulæ.—Eds.

is, no doubt, the line 5412.4 quoted by Professor Pickering from the measurements of Professor Campbell, and H $[D_1\ 2]$ is $H\alpha$. As to H $[S_1\ 2]$ the formula gives $\lambda = 10128.17$, as already calculated by Professor Pickering, and there can be no doubt that the line is to be found in the spectra of stars of the fifth type, the adjacent terms H $[S_1\ 1]$ and H $[S_1\ 3]$ being certainly known. But the first term of the nebulous series, H $[D_1\ 1]$, should have $n=0$, $\lambda=\infty$, if the formula is exact, and then no such line would exist. If, on the contrary, the formula of Balmer is only approximate, we will have a doublet with a greater wave-length than any line we know or can at present infer from any spectrum hitherto investigated.

Besides, the close agreement between the observed and the computed values of H $[S_1\ 1]$ shows clearly that $\mu = 0.5$ is to be preferred to $\mu = 0.500737$, which would give $\lambda = 4698.43$ instead of 4687.88.

LUND, July 28, 1897.

ON TRIPLETS WITH CONSTANT DIFFERENCES IN THE LINE SPECTRUM OF COPPER.

By J. R. Rydberg.

The experience acquired in the examination of a great many spectra shows that the lines which can be arranged in series according to rules already discovered, form but a small portion of the whole number of lines, which we can obtain under different conditions from the same incandescent gas. In the spectra of the biatomic elements I have pointed out, in addition to the ordinary series, regular groups of doublets and triplets closely agreeing in their constitution with the doublets and triplets by which the known series are formed.[1] Here we find constant differences of wave-numbers, nebulous and sharp, simple and compound triplets, and we have strong reasons to assume that these can be united in series analogous with those already known. However, this analogy does not seem equally clear, when we consider the spectra of the heavy metals with their immense numbers of lines, regarding the connection of which we have hitherto been completely in the dark. This applies, for instance, to the spectra of the Fe group, of the Pt group, of Cu, Ag, and Au. So far as we know it is not impossible that the constant differences of wave-numbers are limited to the ordinary series, and that the spectra of higher temperatures are built up in quite another way, so that some new key must be found to make a grouping of the lines practicable.

To decide, if possible, this question I have examined the spectrum of Cu after the measurements of Professors Kayser and Runge,[2] and I have found that the law of constant differences holds good even outside the ordinary series. As the lines which I have hitherto been able to arrange are in general very weak, no trustworthy conclusions can be drawn from their relative

[1] "Recherches sur la constitution des spectres d'émission." *K. Svenska. Vet' Akad. Handl.*, 23, No. 11, 100. *Wied. Ann.*, 52, 119.

[2] "Über die Spectren der Elemente," 5, 8–17.

intensities, but it seems not impossible that we have to do with a constitution differing considerably from any that we have previously known. However, we will retain the word "triplets" to designate recurring groups of three lines with constant differences between the wave-numbers.

In my examination of the Cu spectrum I have met with two different groups of triplets. The *first group* gives the differences $\nu_1 = 129.50$, $\nu_2 = 50.58$, and consists of the following complete triplets.[1]

i *n*	ν_1	*i* *n*	ν_2	*i* *n*
(5d) 26599.07	129.46	(4d) 26728.53	50.47	(5d) 26779.00
(5d) 27196.31	130.28	(6d) 27326.59	51.47	(6n) 27378.06
(5d) 27278.80	129.57	(6d) 27408.37	50.65	(5d) 27459.02
(5d) 28196.50	128.10	(4) 28324.60	49.75	(5d) 28374.35
(6) 29443.03	129.47	(4d) 29572.50	50.63	(5d) 29623.13
(3d) 31987.51	129.76	(5d) 32117.27	51.14	(3d) 32168.41

The first, third and fifth of the triplets give almost the same values for ν, which value I consider as normal. In the second and the six h both ν_1 and ν_2 are greater, in the fourth triplet both are smaller. By analogy this would indicate that the three last-mentioned triplets are really compound, but the components too weak to be observed.

The same differences of wave-frequencies occur also in the following doublets, some of which seem to be intimately connected with adjacent triplets:

i *n*	ν	*i* *n*	*i* *n*	ν	*i* *n*
(2rd) 22026.53	129.76	(5d) 22156.29	(4d) 33083.55	128.89	(4) 33212.44
(5d) 27233.12	129.66	(5n) 27362.78	(5n) 38768.71	130.29	(5d) 38899.00
(5) 30488.83	129.19	(5d) 30618.02	(4) 41663.54	130.07	(2d) 41793.61
(5d) 27620.72	50.52	(6d) 27671.24	(5n) 35885.38	50.55	(5n) 35935.93
(4d) 28297.83	50.46	(4d) 28348.29	(3r) 44185.22	51.21	(4r) 44236.43
(5d) 29392.05	50.98	(6) 29443.03	(5) 45081.39	49.44	(3r) 45130.83
(4d) 30461.99	50.47	(6) 30512.46	(4r) 45833.72	50.26	(4) 45883.98
(5n) 33524.31	50.54	(5n) 33574.85	(6r) 46043.06	50.72	(6) 46093.78

[1] The intensity decreases from 1 to 6; *d* corresponds to "verbreitert," *n* to "sehr unscharf," *r* to "umgekehrt" of Kayser and Runge; the other lines are sharp.

Several of these doublets may be only accidental, without real connection between their components.

The *second group* of triplets has greater differences of wave-frequency, namely, $\nu_1 = 680.19$, $\nu_2 = 212.21$. The following are complete:

i *n*	ν_1	*i* *n*	ν_2	*i* *n*
(4) 18001.28	680.29	(5) 18681.57	212.20	(3) 18893.77
(4n) 18546.37	680.33	(4d) 19226.70	212.10	(5d) 19438.80
(4d) 26728.53	679.84	(6d) 27408.37	212.35	(5d) 27620.72
(5d) 26799.00	680.02	(5d) 27459.02	212.22	(5d) 27671.24
(5) 32319.89	679.82	(5d) 32999.71	212.73	(4) 33212.44
(4) 32532.17	680.37	(4) 33212.44	211.03	(5n) 33423.47
(2r) 45153.25	680.47	(4r) 45833.72	209.34	(6r) 46043.06

In the following doublets we meet with only one of the differences in question:

i *n*	ν	*i* *n*	*i* *n*	ν	*i* *n*
(5n) 20858.41	680.41	(5n) 21538.82	(6) 29443.03	679.63	(4d) 30122.66
(5d) 23571.45	680.50	(5d) 24251.95	(5) 30488.83	680.13	(4) 31168.96
(5d) 24251.95	679.74	(5n) 24931.69	(4n) 31307.04	680.47	(3d) 31987.51
(5d) 26599.07	679.73	(5d) 27278.80	(5n) 31488.03	680.38	(3d) 32168.41
(6d) 27667.80	680.49	(4d) 28348.29	(4d) 31961.85	680.55	(3) 32642.40
(4n) 21287.38	211.94	(2) 21499.32	(6d) 29238.06	212.51	(5d) 29450.57
(5d) 27196.31	212.06	(6d) 27408.37	(5d) 32045.84	212.54	(4d) 32258.38
(6d) 28196.50	212.03	(4d) 28408.53	(5) 32319.89	212.18	(4) 32532.07
(5d) 28374.35	212.52	(5d) 28586.87	(4n) 44502.20	212.52	(6r) 44714.72

In the triplets and doublets the lines 24251.95, 27408.37, 32319.89, 32532.07, and 33212.44 occur twice.

Between the two groups of triplets we find a connection which I have never observed before. As is to be seen from the following arrangement of the wave-numbers with their differences, we have a group of lines similar to the compound triplets of the biatomic elements; save that here both of the two characteristic pairs of differences occur in simple triplets, while in the other case we have one pair only as peculiar to the spectrum.

(5d) 26599.07	129.46	(4d) 26728.53	50.47	(5d) 26779.00
679.73		679.84		680.02
(5d) 27278.80	129.57	(6d) 27408.37	50.65	(5d) 27459.02
		212.35		212.22
		(5d) 27620.72	50.52	(5d) 27671.24

Indications of such groups are met with more than once, but in general they seem to be incomplete.

Among other differences, which appear very frequently, we find a great many which are a little smaller than the known difference 248.54 of the doublets of the ordinary series. Between 238.5 and 245.5, for instance, there are no less than 42. The numbers do not coincide so closely as in the cases already considered, owing, perhaps, to a constitution of the doublets analogous with that we are acquainted with in the nebulous series, so that constant differences would really exist between one of the lines and a weaker companion, not yet observed, of the other. For example, I will give a few pairs of lines in which the concordant character of the constituents seems to indicate a real connection.

i	n	ν	i	n
(2)	21255.02	244.30	(2)	21499.32
($5d_r$)	39008.56	242.99	($5d_r$)	39251.55
($2d_r$)	41548.60	245.01	($2rd_r$)	41793.61
(2r)	44886.33	244.50	(3r)	45130.89

On placing the means of all the constant differences of Cu together in order of their magnitude we find,

ν_1	ν_2
680.19	212.21
248.54	
129.50	50.58

This group of values of ν evidently resembles the corresponding numbers of the Ca group,[1] but we are unable at present to decide whether the resemblance is real or apparent. I have tried in vain to arrange the new triplets in series. At all events there can be no doubt that the law of constant differences extends beyond the limits of the first discovered series. In another

[1] *Wied. Ann.*, 52, 126.

respect also the triplets of Cu must excite interest. Hitherto triplets have been recognized only in the spectra of biatomic elements, and the series of Cu supposed to be made up of doublets like those of elements of uneven valency in general. Now the difference between elements of uneven and of even valency is partly smoothed out, triplets having been found in the former group as well as doublets in the latter.

LUND, August 2, 1897.

RÉSUMÉ OF SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE DURING THE FIRST HALF OF 1897.

By P. TACCHINI.

I GIVE below a résumé of the solar observations made during the first half of 1897. The following results have been obtained for the spots and faculæ:

1897	Number of days of observation	Relative frequency		Relative size		Number of spot groups per day
		of spots	of days without spots	of spots	of faculæ	
January	23	13.61	0.00	108.0	70.2	2.9
February	19	9.00	0.00	59 5	74.7	2.6
March	24	8.8	0.04	26.5	62.5	2.8
April	25	10.44	0.12	30.1	67.7	3.3
May	25	5.72	0.20	29.5	55.4	1.6
June	29	3.14	0.31	13.1	48.1	2.0

Sun-spots have thus continued to diminish in number with a secondary minimum in the month of June; in correspondence with this diminution we find an increase in the number of days without spots. In the case of the faculæ we also have a minimum in the month of June, but the difference between this and the preceding series is not so well marked as for the spots.

For the prominences we have obtained the following results:

1897	Number of days of observation	Prominences		
		Mean number	Mean height	Mean extent
January	14	3.71	37.2	2.1
February	15	4.47	33.1	1.5
March	19	5.42	38.3	1.8
April	21	3.86	34.9	1.4
May	23	3.30	33.2	1.4
June	28	4.00	36.6	1.4

It thus appears that even the prominences have experienced a diminution of activity. The highest prominence observed

(January) reached an altitude of 93″, and not a single prominence is worthy of special remark.

For the distribution in latitude of the various phenomena I have obtained the following data, grouped by zones for each quarter:

1897

Latitude	Prominences		Faculæ		Spots	
	First quarter	Second quarter	First quarter	Second quarter	First quarter	Second quarter
90°+80°	0.004	0.000				
80 +70	0.008	0.003				
70 +60	0.008	0.003				
60 +50	0.050	0.087	0.000	0.004		
50 +40	0.034 } 0.381	0.083 } 0.545	0.000	0.000		
40 +30	0.067	0.056	0.032 } 0.403	0.021 } 0.410		
30 +20	0.050	0.125	0.069	0.057	0.000	
20 +10	0.059	0.118	0.127	0.119	0.122 } 0.367	0.000 } 0.351
10 + 0	0.101	0.070	0.175	0.209	0.245	0.351
0 −10	0.156	0.098	0.185	0.246	0.306	0.433 } 0.649
10 −20	0.169	0.090	0.196	0.193	0.286 } 0.633	0.216
20 −30	0.139	0.101	0.100	0.098	0.041	
30 −40	0.038	0.049	0.063 } 0.597	0.024 } 0.590		
40 −50	0.063 } 0.619	0.066 } 0.455	0.048	0.021		
50 −60	0.042	0.031	0.005	0.008		
60 −70	0.004	0.007				
70 −80	0.008	0.003				
80 −90	0.000	0.010				

While the faculæ and spots show in the two quarters a greater frequency in the southern zones, the frequency of the prominences has been a little greater for the northern hemisphere in the second quarter. Prominences have been seen in almost all the zones, while the faculæ have been confined within the limits ±60°, and the spots within the zones (+20°—30°). I have observed no eruptions during the six months, and on the spots I noted merely the reversal of the lines D_1, D_2 on the 14th of January over the great spot near the western limb. One might therefore almost affirm that the constitution of Sun-spots has undergone a change!

Rome, August 20, 1897.

HELIOGRAPHIC POSITIONS. I.

By Frank W. Very.

The study of the solar surface is now and must continue to be a very important department of astrophysics. With the possible exception of the human brain, there is no more wonderful object in nature than the Sun, but only those who, with the aid of a powerful telescope and rare atmospheric quiescence, have been able to gaze for hours on the majestic turmoil of a great Sun-spot in full vigor, can appreciate the fascination which attaches to this study. Such favored ones will recognize that, while the investigation of the intimate surface structure of the Sun by Secchi, Langley, Janssen, Young, and others, together with the consecutive researches of solar history by Carrington, Spoerer, Wolf, De La Rue and Stewart, Tacchini, and the Greenwich observers, have given us a basis of firmly established facts, we have scarcely begun to realize the meaning and the variety of the phenomena involved; and only minute and assiduous study will open the solar secrets further. The beginner in such studies can at first do little more than familiarize himself with the leading facts by actual observation, and verify the conclusions of his predecessors. Even this demands a very considerable outlay of time and patience, and it is for such students that I propose to review the initial steps for obtaining accurate positions on the solar surface. No especial claim is made for originality, but I shall endeavor to gather into one body a considerable mass of scattered information, and, whatever else may be lacking, to at least present this material in an intelligible form. I find that the relative positions of points on the Sun-sphere, although governed by elementary considerations, are sufficiently intricate to be difficult of retention in the memory, and judging from their published figures, many professional astronomers share in my failing. I trust, therefore, that the details given here may not seem superfluous.

In photographing the Sun it will usually be most convenient to adopt a fixed distance for the photographic plate, or at least a distance which varies only with the temperature, and which is determined experimentally as the one giving the sharpest focus with the given optical apparatus and the particular photographic film employed. The diameter of the image will in this case vary from day to day, and each picture must be reduced separately. The labor, however, can be minimized by preparing suitable tables.

Where the method of Sun-drawing upon a solar projection is employed, it is best to adopt a convenient diameter for the solar image of an exact number of scale units (*e.g.*, 20^{cm}, 8 inches, ½ foot, or some such number) for convenience in reduction, adhering to this magnification throughout the entire series. Circles of the adopted size may be drawn in advance upon white paper. The paper is pinned upon a drawing board, sliding on rigid guides attached to the telescope and with its plane perpendicular to the optical axis. The distance of the paper is varied from day to day so that the carefully focused solar image shall fit the circle, giving a constant scale of linear distances at the Sun's surface, though a variable one for angular measures on the celestial sphere. A shield of black cardboard, about three feet square, attached to the telescope, gives sufficient shade to the drawing board if indoors, but in the open air a closed canopy of black cloth may be needed. The position and outlines of spots are traced while the clock-driven telescope keeps the image coincident with the bounding circle of the projection. If a horizontal meridional heliostat is used, it will be necessary to rotate the drawing in the plane of projection about the optical axis, and to work rapidly. This arrangement is consequently ill-adapted to anything but instantaneous photography; and for hand work there are advantages in the coelostat, rotating at half speed and sending the sunbeam east or west.

A series of four double charts in orthographic projection, showing positions of meridians and parallels for every 10°, to 40° north and south latitude, on a scale of five inches to the

solar diameter, has been published by Ball in his *Atlas of Astronomy*.[1] These are really equivalent to eight single charts, since each can be used upside down, and they permit the determination of heliographic positions by inspection to within a degree or two, which in view of the rapid changes in Sun-spots is nearly accurate enough for general positions, but not for the detailed study of the changes in question which are of sufficient interest to be pursued for their own record and elucidation. If greater accuracy should be desired by this method, a series of seven double charts, one for each degree of the varying inclination of the Sun's equator to the ecliptic, might be constructed, and such a series would be sufficient for reading spot-positions in Sun-drawings to something less than a degree, but the method is necessarily of limited value.

Photographs are worthy of more precise treatment, and here, if the image has been projected by an eyepiece, the distortion of the field becomes appreciable. A very good way to determine the correction for distortion is to take chronographic transits of both limbs of the Sun, or of a small spot, across a system of lines, ruled parallel at a distance $s = \frac{1}{4}$, or $\frac{1}{2}$ inch apart, or in general at some interval not far from a minute of arc, and placed at right angles to the solar motion at the distance of the usual projection. We will suppose that one of these lines, which may be called the central line, intersects the optical axis, and the lines to be so equally spaced that the time of passage across the central line coincides with the mean for the symmetrically disposed system. We then take the mean (for both limbs) of the time-intervals from mean passage as determined from the combination of all the transits. The correction for the instrumental variation in the direction of the Sun's path in a meridional heliostat image is scarcely appreciable in so short an interval, and is nonexistent in an equatorial image; but that for the Sun's motion in right ascension must be applied. Five series of double transits of the Sun's limbs across a system of twenty-five parallel lines, or ten series of transits of a spot, will be sufficient. For some purposes

[1] Published by D. Appleton & Co., New York, 1892.

we may wish to state the distortion-correction as a function varying from zero at the center to its maximum value at the edge of the field, or at the radius (R) of the solar image. Here it will be well to make a larger number of observations of the transit across a central interval, or across the two intervals on either side of the central line, the mean (I_1) being assumed to represent the time-interval for an undistorted image, and this, multiplied by the number of spaces to the edge of the solar image (n_R), gives a computed interval,

$$I_{R'} = I_1 \; n_R = I_1 \; \frac{R}{s} \, ,$$

whose ratio to the time of passage of the semi-diameter is a number, having an excess above unity which is the distortion at a distance from the center of the field equal to the radius of the Sun's image, the ratio of times being also an expression in terms of the linear radius in this particular case. The distortion may be converted into inches or centimeters on the scale of projection by multiplication by the number of these units in the radius of the solar image, or may be stated in seconds of arc by multiplying by the tabular value of the Sun's radius in seconds (R''). In like manner the distortion at any point in the field (whose radius is r) may be expressed as a percentage of the corresponding radius of an undistorted field (r') by multiplying the mean interval for a central space by the number of spaces to the given radius,

$$I_1 \, n = I_{r'} \, ,$$

and comparing with the observed interval from central passage (I_r). A point in the solar image at the real radius (r') will be found in the distorted image at

$$r = \phi \; (r').$$

In comparing distances and intervals, we see that

$$r : r' = \int_0^{r'} \phi \, (r') \, dr' \; : r' = I_{r'} : I_r,$$

that is to say, the greater the distortion or magnification of a given part of the telescopic image, the shorter will be the transit

interval for the corresponding fraction of the normal transit, the times of transit being proportional to the distances. The distortion at the radius r' (expressed as a fraction of the undistorted radius) is:

$$\frac{r - r'}{r'} = \frac{I_{r'} - I_r}{I_r};$$

and the correction to the measured radius (r), required on account of distortion, is:

$$\frac{r' - r}{r} \times r = \frac{I_r - I_{r'}}{I_{r'}} \times r,$$

subtractive if the distortion has increased the size of the image The corrected radial distance is therefore:

$$r' = r + \left(\frac{I_r}{I_{r'}} - 1\right) r = r \times \frac{I_r}{I_{r'}}.$$

Inasmuch as we do not wish to get the final value of the radius in linear units, but as a fraction of the solar semi-diameter $\left(\frac{r}{R}\right)$, and since the time of passage of the semi-diameter is the same in a distorted as in an undistorted image, the correction for distortion, as applied to the ratio $\frac{r}{R}$, is zero at the center of the solar disk and at the limb (it being assumed that the solar image is central in the field) and attains a maximum at a little over half the radius of the disk. For the radius r, the observed interval from central passage, expressed as a fraction of the time of passage of the semi-diameter, is $\frac{I_r}{I_R}$; and since the time-intervals are proportional to the real distances, this is also the corrected value of $\frac{r}{R}$. The ratio of the computed intervals for an undistorted image is the same as the ratio of the distances, or

$$\frac{n_r I_1}{n_R I_1} = \frac{r}{R},$$

and the disagreement of computed and observed intervals is the evidence of distortion. That is to say, the point whose position in the distorted image has the fractional radius $\frac{r}{R}$, will not

exhibit a corresponding ratio of intervals, but will be found in an undistorted image at $\frac{r'}{R'} = \frac{I_r}{I_R}$. The distortion of the fractional radius is therefore

$$\frac{r}{R} - \frac{r'}{R'} = \frac{r}{R} - \frac{I_r}{I_R}.$$

and the correction to be applied to the distorted fractional radius is:

$$\frac{r'}{R'} - \frac{r}{R} = \frac{I_r}{I_R} - \frac{r}{R},$$

or the corrected value of $\frac{r}{R}$ is:

$$\frac{r'}{R'} = \frac{I_r}{I_R}.$$

If, as before, distortion has increased the size of the image, $\frac{I_r}{I_R} > \frac{r}{R}$, or the value of $\frac{r}{R}$, obtained on the erroneous assumption that the image is undistorted, is too small, whence the correction to $\frac{r}{R}$ is positive.[1]

The value of the radius at any point of the solar disk, expressed in seconds of arc, is:

$$r'' = \frac{I_r}{I_R}\left(R''\right),$$

and the correction to the radius in seconds (where the measurement has been made on the erroneous assumption of no distortion in the image) is:

$$c'' = \left(\frac{I_r}{I_R} - \frac{r}{R}\right) \times \left(R''\right),$$

where, as before, I_R is the observed time of passage of the semi-diameter, and R'' the tabular radius of the Sun in seconds of arc.

The scale-value (V_o'') in seconds of arc per linear unit at the center is:

[1] The accompanying note p. 259 by Mr. F. Slocum, a student at this Observatory will illustrate the application of these principles.

$$V_O'' = m\left(\frac{R''}{R}\right) = \frac{I_1}{I_R} \times \left(\frac{R''}{s}\right).$$

whence, at the center, the multiplier (m) is:

$$m = \frac{I_1\ R}{I_R\ s};$$

but at any any other point of radius r,[1] the scale-value will vary according to the equation

$$V_r'' = m\left[\frac{1}{R} + \frac{r}{R}\left(\frac{I_r - I_{r'}}{I_{r'}}\right)\right] \times \left(R''\right).$$

The multiplier (m) is a variable, but an approximate average value can be found for it by taking the ratio of computed and observed intervals corresponding to the radius at the center of gravity of the area included in the plotted distortion curve. The values computed in this way may need a little adjustment by comparison of the integrated radii (obtained by summing the scale-value for short intervals) with the true radii,

$$r'' = \frac{I_r}{I_R}\left(R''\right).$$

Having obtained the scale-values in seconds, it is a simple matter to transform them into miles measured at the Sun's surface. The distance to be used is, of course, that from the Sun's surface to the Earth.

Position-angles in either drawings or photographs are readily measured with the protractor, and need only a passing mention.

The correction for distortion of field is not appreciable where no eyepiece is applied, unless the field is much greater than is ever employed in practice; but for projection-images, formed by the aid of eyepieces, the correction is required in accurate work for all but very narrow fields near the optical axis. In work with the position filar micrometer, since the eyepiece is merely used to examine the field of the objective, no correction for distortion is needed. With this instrument, therefore, we may measure spot-positions directly in polar coördinates.

[1] For the particular case of the marginal radius, $V_R'' = V_O'' + \frac{I_R - I_{R'}}{I_{R'}}\left(R''\right)$

Sun-drawings made upon paper by the method of projection cannot pretend to very great accuracy, even when most carefully executed. Paper is hygroscopic, and, when placed in a warm solar image, changes its dimensions, even if there be no variation of humidity between the observing and computing rooms. To avoid this buckling and distortion of paper by the Sun's heat, Mr. Carrington made all of his long series of Sun-drawings upon ground glass, with an image eleven inches in diameter, all measurements being made either on the ground glass (coated with whitewash, tinted yellow and backed by dead black paper) or by the method of timing to be described presently. The drawings were transferred to paper for preservation, but no measures of accuracy were made from these paper relics.

The method of timing "grew out of a somewhat rude notion of making the disk of the Sun its own circular micrometer." A pair of cross-wires being placed at right angles to each other, approximately 45° to the north and south line, and at the focus of the telescope, the times of transit of the Sun's limbs, and of a spot, may be taken to determine the direction of the Sun's path and the position of the spot. For example, if the experiment be made at the solstices, the Sun will move along a declination, parallel, and assuming that the Sun's center does not pass directly over the intersection of the wires, or that these are not exactly 45° to the north and south line, we shall have first contact of the preceding limb at one of the wires, which may be called A, the other being B. Let the times of contact in their order be A_1, B_1, A_2, B_2. Then calling α the angle made by wire A with a normal to the Sun's path, or with an hour-circle if the deviation of the Sun's path from an east and west line, and the variation of the refraction be neglected,

$$\tan \alpha = \frac{A_2 - A_1}{B_2 - B_1},$$

During the half year preceding the summer solstice, a line through the intersection of the cross-wires, at right angles to the Sun's diurnal path, will incline towards the east of north, and towards the west in the second half of the year. Hence a cor-

rection for the deviation of the Sun's path must at such times be applied to a, which is:

$$\kappa = \frac{\Delta\delta}{15 \cdot \sin p \times 3600 \times \sin 1''},$$

where $\Delta\delta$ is the Sun's hourly increment of declination given in seconds of arc, and p is the north polar distance of the Sun. The position-angle of wire A is therefore $a \pm \kappa$, the sign of κ being positive from winter to summer solstice, and negative the rest of the year.

Mr. Carrington has given[1] a formula by which the angle a may be corrected for differential refraction. Calling a' the corrected angle,

$$\tan a' = \tan a \cdot \sqrt{\frac{1 - e^2 \cdot \cos^2(a + s)}{1 - e^2 \cdot \sin^2(a + s)}},$$

in which s is the Sun's parallactic angle, positive for west hour-angles, and negative for east, while e is the eccentricity of the solar disk due to refraction. The correction is of troublesome application, and may be safely neglected in most observations, since the atmospheric tremor will seldom permit work at the low altitudes where the consideration of this correction becomes imperative.

If A denotes also the point on wire A where the center of the Sun crosses, and B is the corresponding point on wire B, the times of the transit of the center are:

$$\text{at } A \text{ - - - - - } \tfrac{1}{2}(A_1 + A_2),$$
$$\text{at } B \text{ - - - - - } \tfrac{1}{2}(B_1 + B_2),$$

and the interval is:

$$AB = \tfrac{1}{2}(B_1 + B_2) - \tfrac{1}{2}(A_1 + A_2).$$

The time of transit of the center over the normal to the Sun's path through the intersection of the cross-wires is:

$$T = \tfrac{1}{2}(A_1 + A_2) + AB \sin^2 a.$$

[1] R. C. CARRINGTON, *M. N.*, 14, 155, 1854.

[2] In the original, a was supposed to be measured from the east and west line, giving s the opposite sign.

The diameter of the Sun will be

$$2R = 15 \cdot \sin p \, (B_2 - B_1) \sin \alpha \,,$$

or if wire B make an angle with wire A, which is not exactly 90°, but $90° + \theta$, the Sun's diameter is

$$2R = 15 \cdot \sin p \, (B_2 - B_1) \sin \alpha \cdot (1 \pm \tfrac{1}{2} \sin \theta),$$

the sign of $\tfrac{1}{2} \sin \theta$ changing if the cross-wires are rotated through 90°, thus interchanging wires A and B. The angle θ may evidently be determined by making this interchange.

If D is the distance from the intersection at which the center crosses the normal to the Sun's path,

$$D = AB \cdot \cos \alpha \cdot \sin \alpha \,.$$

T and D being the normal interval and distance for the Sun's center, while t and d are the same for a Sun-spot, the spot's coördinates relatively to the center are:

In right ascension $\quad 15 \cdot \sin p \; (t - T)$,
In north polar distance $15 \cdot \sin p \; (d - D)$,

all quantities being finally expressed in seconds of arc. These values may be transformed into polar coördinates. As in the case of micrometric measures they require no correction for distortion.

For a more complete elucidation of these formulas, the original paper by Carrington, already cited, should be consulted.

In his larger work[1] Mr. Carrington deprecates the establishment of an east and west line on a Sun-drawing by allowing a spot to run across with telescope fixed, noting its path, and undoubtedly the method described by him is more accurate; but if care be taken that the spot shall make a central transit, avoiding whatever curvature of path is produced by the distortion of the field, and subsequently applying the correction for the Sun's motion in declination, the trace of a transiting spot is probably as accurate as the other steps in the production of a projection-drawing, at least if nothing better than paper is used in making the sketch.

[1] R. C. Carrington, *Observations of the Spots on the Sun from November 9, 1853 to March 24, 1861, made at Redhill.* London, 1863.

One especial advantage in the employment of the diagonal transit wires, as advocated by Carrington, is that the chromatic separation of images acts in the direction of the radial cross-wires, while the contacts observed are at right angles to the same direction. Errors due to imperfect achromatism are therefore minimized. If the transits are repeated several times and their mean values taken, the irregularities of measured positions due to the almost universal diurnal atmospheric tremor will be largely eliminated. Accuracy in hand drawings is greatly hindered by tremor, and to such an extent that little advantage is gained by magnifying the image above a diameter of six or eight inches, although but for this trouble there should be increased precision with larger magnification. Instantaneous photography and the method of repeated transits will overcome the difficulty to a great extent.

Carrington's method does not give good results when a spot is near the limb. The micrometric measurement of the spot's distance from the limb $(R-r)$, as described by Secchi in his work on the Sun, is then to be preferred. In this case no correction for distortion is needed, but to preserve the micrometer from injury and loss of accuracy through changes of dimension by the heat, special holders and screens are needed, and the wires are preferably made of fine platinum, since if of combustible material the full aperture can scarcely be used. "As it is impossible to know the direction of the center exactly, we dispose the micrometer in such a way that one of its wires may be perpendicular, the other tangent to the limb. It is better that the second [parallel] wire should encroach a little upon the disk [in the preliminary adjustment]. We shall then be able to judge by the equality of its two segments when the recticule is properly placed."[1]

The photographic method, employing a horizontal telescope and heliostat, permits the very exact orientation of the image by the simultaneous photographing of the shadow of a plumb-line of fine wire, suspended in front of the photographic plate and

[1] A. SECCHI, *Le Soleil*, p. 83, Paris, 1870.

almost in contact with it. The position of the north and south line on the image follows immediately by the application of the usual formulas for the parallactic angle.

While photographs are to be preferred, the comparison of the results from carefully made drawings by Rev. S. J. Perry[1] shows that the drawings are not very far behind, and for training the observing powers of the student they are indispensable.

All that precedes relates to the determination of positions in a solar image in plane polar coördinates. The transformation of these coördinates will be considered in another article.

LADD OBSERVATORY,
Providence, R. I., July 1897.

[1] S. J. PERRY, "Photographs and Drawings of the Sun," *Mem. R. A. S.*, **49**, 273, 1889.

Minor Contributions and Notes.

HARVARD COLLEGE OBSERVATORY. CIRCULAR NO. 18.

VARIABLE STAR CLUSTERS.

Announcement was made in *Circular* No. 2 of the discovery by Professor Solon I. Bailey of numerous variable stars in certain globular stellar clusters, and their absence in other objects which apparently belong to the same class. Since then he has found many more of these variables, so that their total number, including a few found here, is now 310, distributed as follows:—In *N. G. C.* 104 (47 Tucanae), 6; in 362, 8; in 1904,1; in 5139 (ω Centauri), 60; in 5272 (Messier 3), 113; in 5904 (Messier 5), 63; in 5986, 1; in 6254, 1; in 6266, 9; in 6626, 3; in 6656, 5; in 6723, 2; in 6752, 1; in 7078, 27; 7089, 8: and in 7099, 2. In the greater portion of these clusters about 1000 stars were examined. In Messier 3 about one-ninth of the stars are variable, while in others like *N. G. C.* 6205 (the great cluster in Hercules), out of nearly 2000 stars not a single variable has been found. The positions of 62 of the stars in Messier 5 are given in the *Harvard Observatory Annals*, XXVI, 243, 246. The light curve and period of one of them are given in the *A. N.*, **140**, 285.

SOUTHERN DOUBLE STARS.

A distinguishing feature of the climate of Arequipa is the great steadiness of the air. The value of this location as an observing station is largely due to this fact. Good definition, under high powers, is obtained there on many more nights than in Europe, or in the United States, where nine-tenths of the observatories of the world are at present located. A search for close double stars may, therefore, be advantageously made at Arequipa, and accordingly, in 1891 all the stars of the sixth magnitude and brighter, south of declination —30°, were examined for close companions. The stars in one quarter of the region, and included between 12^h and 18^h of right ascension were examined by Professor William H. Pickering, and the remaining three-quarters by Professor Solon I. Bailey. The instrument used was the 13-inch Boyden telescope. A power of 450 was ordinarily employed.

The stars whose numbers in the Argentine General Catalogue are given below were found to have companions whose distances were estimated not to exceed 30″. Stars already announced as double in the catalogues of Herschel and Russell are not included. When two or more companions were noted the letter T is inserted after the number:—

A. G. C. 451 T, 480 T, 684, 702, 780, 1024 T, 1197, 2412, 2992, 3487 T, 4368, 4395, 4845, 5295, 6494, 6633, 7914, 7990 T, 8093 T, 9234, 10188, 10335, 10496, 11097, 11712, 11727, 11887, 12035, 12101, 12180, 13135, 15795, 16200, 16541 T, 16612 T, 16690 T, 16793, 16845, 16992, 17403, 17440, 17504, 17541 T, 17572, 17907, 17936, 18174 T, 18492 T, 18700, 18773, 18863 T, 18931 T, 18980, 19129, 19273 T, 19280, 19295, 19540 T, 19578 T, 19597 T, 19679, 19697, 19741, 19746, 19873, 19916, 19934 T, 19980, 19988, 20049, 20170, 20203, 20444 T, 20466 T, 20649, 20695, 20806 T, 20811, 20861, 20909 T, 21078 T, 21153, 21177, 21319 T, 21374, 21421 T, 21499 T, 21559, 21694 T, 21767, 21828, 21887, 21921, 21974, 21995, 22124, 22159, 22534 T, 22582, 22598, 22604, 22949, 22970, 23018, 23035 T, 23098, 23126 T, 23358, 23397 T, 23448 T, 23486, 23515 T, 23549 T, 23597 T, 23603 T, 23785 T, 23973, 24148, 24182, 24218, 24407 T, 24483, 24557, 24570, 24624, 24703, 24888, 25137, 25259, 25527, 25548, 26026 T, 26041, 26287, 27354, 27909, 28851, 29314, 29368, 30425, 30814, and 32446.

SPECTRUM OF ζ PUPPIS.

In *Circular* No. 16 it was shown that a line having wave-length 5413.9 probably exists in the spectrum of this star. This line is clearly visible on three photographs of this star taken in Arequipa on isochromatic plates.

EDWARD C. PICKERING.

JULY 29, 1897.

NOTE ON THE DISTORTION DUE TO THE LENS IN A PROJECTION DRAWING.

THE following observations were made in connection with a series of projection-drawings of the Sun with a 12-inch equatorial. An image of the Sun, of three inches radius, was allowed to pass over twenty-five parallel lines, one-quarter inch apart, carefully adjusted perpendicular to the direction of the Sun's motion. The times of passage over each line of both limbs and a few small spots were recorded by the chronograph. The time-intervals from the center

were found, and the correction for the Sun's motion applied. The means of the time-intervals from the center to the limb were taken and divided in succession by the largest, *i. e.*, by the time corresponding to the passage of the radius. This gives the percentage of times, and these are compared with the percentage which would be found if there were no distortion. This latter is the same as the percentage of linear intervals, and is found by dividing the distances from the center by the radius. The differences between these two percentages give the corrections to $\frac{r}{R}$ in Carrington's notation, where r is the distance of the spot from the center of the projected image, and R is the radius of the projection.

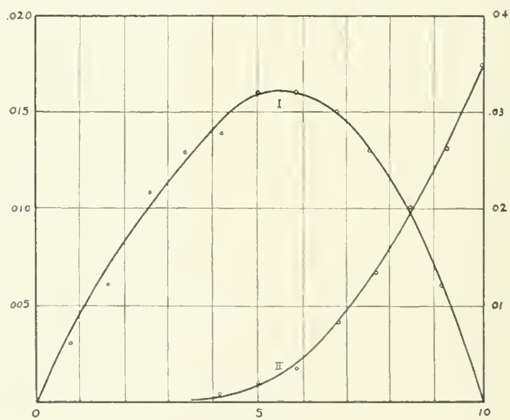

FIG. 1.

Curve I, Fig. 1, has for ordinates these corrections and for abscissæ the distances from the center.

To find the correction in inches to any distance on the projection measured from the center, the mean intervals of times, corresponding to the same radius as found from the transit observations across the parallel lines, were compared with the intervals corresponding to an undistorted image. These were found by considering the center of

Line	Transit intervals										Mean	Sun's motion	Corrected mean
	Limb 1	Limb 2	Limb 1	Limb 2	Limb 1	Limb 2	Limb 1	Limb 2	Spot	Spot			
	s	s	s	s	s	s	s	s	s	s	s	s	
1	66.65	66.03	66.65	65.84	66.76	65.88	66.91	65.70	66.30	66.71	66.34	0	66.34
2	61.60	60.78	61.55	60.69	61.58	61.38	61.61	61.50	61.35	61.61	61.36	—.01	61.35
3	56.25	55.95	55.85	55.94	56.08	55.93	56.26	55.85	55.85	56.36	56.03	—.03	56.00
4	50.83	50.65	50.75	50.74	50.98	50.78	50.81	50.80	50.85	51.11	50.83	—.04	50.79
5	45.25	45.35	45.25	45.14	45.38	45.33	45.31	45.40	45.50	45.51	45.34	—.06	45.28
6	39.99	40.00	40.00	40.04	40.18	39.93	39.86	39.90	39.80	39.96	39.96	—.07	39.89
7	34.54	34.05	34.35	34.34	34.33	34.43	34.46	34.40	34.20	34.51	34.42	—.08	34.34
8	28.75	28.88	28.85	28.79	28.73	28.93	28.86	28.90	28.85	28.81	28.84	—.10	28.74
9	22.90	23.05	23.15	23.14	23.03	23.28	23.01	23.30	23.10	23.11	23.11	—.12	22.99
10	17.45	17.55	17.35	17.64	17.58	17.58	17.61	17.55	17.50	17.26	17.51	—.13	17.38
11	11.40	11.82	11.75	11.89	11.68	11.78	11.71	11.70	11.80	11.61	11.71	—.15	11.56
12	5.93	5.80	6.05	6.12	5.98	6.18	6.21	6.10	6.05	6.26	6.07	—.16	5.91
13	.05	.55	.05	.44	.08	.38	.31	.20	.30	.16	.25	—.18	.07
14	5.86	5.25	5.85	5.86	5.72	5.72	5.79	5.75	5.90	5.69	5.74	—.19	5.55
15	11.65	11.70	11.65	11.61	11.72	11.52	11.39	11.80	11.30	11.49	11.58	—.21	11.37
16	17.65	17.65	17.37	17.46	17.57	17.52	17.79	17.50	17.10	17.49	17.51	.22	17.29
17	23.05	23.10	23.20	22.86	23.27	22.82	23.19	23.00	23.20	23.19	23.09	—.24	22.85
18	28.61	28.70	28.75	28.46	28.72	28.42	28.79	28.60	28.72	28.99	28.71	—.25	28.46
19	34.45	34.10	34.25	34.36	34.52	34.42	34.39	34.45	34.20	34.59	34.37	—.27	34.10
20	39.94	40.00	39.77	40.06	39.97	39.77	39.99	39.90	40.15	39.94	39.95	—.28	39.67
21	45.40	45.35	45.40	45.46	45.72	45.32	45.79	45.45	45.45	45.49	45.48	.30	45.18
22	50.85	50.50	50.95	50.56	50.72	50.72	50.89	50.75	50.80	51.04	50.78	—.31	50.47
23	56.21	56.10	56.05	56.06	56.22	56.32	56.29	56.10	56.15	56.54	56.20	—.33	55.87
24	61.46	61.20	61.65	61.21	61.67	61.37	61.79	61.35	61.50	61.69	61.49	—.34	61.15
25	66.52	66.70	66.55	66.91	66.62	66.52	66.79	66.80	66.70	66.79	66.69	—.36	66.33

Mean of intervals from center	Percentage of times	Percentage of distances	Correction to $\frac{r}{R}$	Distance from center	Mean of intervals from center	Corresponding intervals taking 5s.73 as unit for ¼ inch.	Differences	Corresponding value in inches. Correction to measured distance from center
s				in.	s	s	s	in.
66.34	1.00	1.00	+0	3.00	66.34	68.76	2.42	−.106
61 25	.923	.917	+.006	2.75	61.25	63.03	1.78	−.077
55.94	.843	.833	+.010	2.50	55.94	57.30	1.36	−.059
50.63	.763	.750	+.013	2.25	50.63	51.57	.94	−.041
45.23	.682	.667	+.015	2.00	45.23	45.84	.61	−.027
39.78	.599	.583	+.016	1.75	39.78	40.11	.23	−.010
34.22	.516	.500	+.016	1.50	34.22	34.38	.16	−.007
28.60	.431	.417	+.014	1.25	28.60	28.65	.05	−.002
22.92	.346	.333	+.013	1.00	22.92	22.92	0	0
17.34	.261	.250	+.011	.75	17.34	17.19	[15]	[007]
11.46	.173	.167	+.006	.50	11.46	11.46	0	0
5.73	.086	.083	+.003	.25	5.73	5.73	0	0
	0	0	+0	.0				
			See curve No. I					See curve No. II

the image as undistorted, and taking the time of passage over the middle space as the unit of time for each space. The differences between these times were found and reduced to inches by dividing by four times the central unit, since this unit corresponds to one-fourth of an inch.

Curve II, Fig. 1, has for ordinates these corrections, and for abscissæ the distances from the center.

The results tabulated are self-explanatory.

FRED SLOCUM.

PROVIDENCE, R. I.,
May 1897.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO, BULLETIN NO. 3.

DEDICATION OF THE YERKES OBSERVATORY.

THE following additions should be made to the programme of the dedication of the Yerkes Observatory published in the last number of the ASTROPHYSICAL JOURNAL.

The principal scientific address to be made at the Observatory on

October 21, in connection with the formal presentation of the building and instruments to the University of Chicago, will be delivered by Professor James E. Keeler, Sc. D., Director of the Allegheny Observatory. The subject of the address is "The Importance of Astrophysical Research, and the Relation of Astrophysics to other Physical Sciences."

The subject of Professor Newcomb's address, which will be delivered at the University of Chicago on the following day, is "Aspects of Modern Astronomy."

On Monday evening, October 18, Professor S. W. Burnham will show selected double stars with the 40-inch Yerkes telescope. This part of the programme, in common with others involving telescopic observations, is, of course, subject to change in the event of unfavorable weather.

Professor Simon Newcomb will speak at the conferences on a subject to be announced later.

Professor Comstock has changed the title of his paper to "Researches at the Washburn Observatory." It will be presented on Tuesday, Oct. 19, instead of Wednesday, as previously announced. Professor Comstock will exhibit a new form of double-image micrometer.

The title of Dr. Laves second paper has been changed to "Researches on Planet 3.34."

George E. Hale.

Yerkes Observatory,
September 1897.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. The Sun.

Hadden, D. E. Solar Observations, 1895-6. Pub. A. S. P. **9**, 77-85, 1897.

Hale, George E. Note on the Relative Frequency of the H and K Lines in the Spectrum of the Chromosphere. Ap. J. **6**, 157-158, 1897.

Lockyer, J. Norman. The Approaching Total Eclipse of the Sun. Nat. **56**, 154-157, 175-178, 1897.

MacDowall, Alex. B. Sonnenflecke und Luft-Temperature. Meteorolog. Zeit. **14**, 278, 1897.

Mascari, A. Sulla frequenza e distribuzione in latitudine delle macchie solari osservate all' Osservatorio di Catania nel 1895. Mem. Spettr. Ital. **26**, 45-60, 1897.

Maunder, E. W. Total Solar Eclipse, January 22, 1898. English Preparations. Pub. A. S. P. **9**, 131-134, 1897.

Perrine, C. D. Some Recent Sun-spots. Pub. A. S. P. **8**, 225-227, 1896.

Quimby, A. W. Sun-spot Observations. A. J. No. 407, **17**, 183-184. 1897.

Riccò, A. On the Level of Sun-spots and the Cause of their Darkness. Ap. J. **6**, 91-94, 1897.

Rizzo, G. B. Misure assolute del calore solare fatte alla capanna "Regina Margherita" nel Monte Rosa. Mem. Spettr. Ital. **26**, 79-93, 1897.

Rydzewski, Alexander. Total Eclipse of August 9, 1896. Pub. A. S. P. **8**, 297-303, 1896.

Tacchini, P. Sulla distribuzione in latitudine dei fenomeni solari osservati nel 2° trimestre del 1897 al Regio Osservatorio del Collegio Romano. Mem. Spettr. Ital. **26**, 94-99, 1897.

TACCHINI, P. Macchie e faco e solare osservate al R. Osservatorio del Collegio Romano durante il 2 trimestre del 1897. Mem. Spettr. Ital. **26**, 65–68, 1897.

TACCHINI, P. Sulle protuberanze solari osservate al R. Osservatorio del Collegio Romano durante il 2° trimestre del 1897. Mem. Spettr. Ital. **26**, 69–70, 1897.

TACCHINI e RICCÒ. Immagini spettroscopische del bordo solare desegnate a Catania e Roma nei mesi di agosto e settembre del 1895. Tavola CCCXXXIII. Mem. Spettr. Ital. **26**, 1897.

TACCHINI e RICCÒ. Immagini spettrali del bordo solare osservate a Catania e Roma nei mesi di novembre e dicembre, 1895. Tavola CCCXXXV. Mem. Spettr. Ital. **26**, 1897.

YOUNG, C. A. On the Reversing Stratum and its Spectrum, and on the Spectrum of the Corona. Ap. J. **6**, 155–157, 1897.

3. STARS AND STELLAR PHOTOMETRY.

FENET, LÉON. L'Amas du Toucan. Bull. Soc. Astr. France, 257–261, July, 1897.

FOWLER, A. A New Classification of Stellar Spectra (Review). Nat. **56**, 206–208, 1897.

O'HALLORAN, ROSE. Observations of Variable Stars. Pub. A. S. P. **8**, 254, 1896.

O'HALLORAN, ROSE. Maximum of *o* Ceti, 1896–7. Pub. A. S. P. **9**, 86–109, 1897.

HUSSEY, WILLIAM J. Nova Centauri, etc. Pub. A. S. P. **8**, 220–222, 1896.

LOCKYER, J. NORMAN. The Chemistry of the Hottest Stars. Nat. **56**, 91–92, 1897.

PARKHURST, HENRY M. Notes on Variable Stars — No. 18. A. J. No. 403, **17**, 147–149, 1897.

PARKHURST, J. A. Maxima and Minima of Long-Period Variables. A. J. No. 405, **17**, 167–168, 1897.

PARKHURST, J. A. Maximum of 2815 U Geminorum. A. J. No. 407, **17**, 182, 1897.

4. STELLAR SPECTRA, DISPLACEMENTS OF LINES AND MOTIONS IN THE LINE OF SIGHT.

GRUS, G. Spectroskopische Beobachtungen einiger Sterne. Prag, 1897.

MONCK, W. H. S. The Spectra and Proper Motion of Stars. Pub. A. S. P. **9**, 123–128, 1897.

5. Planets, Satellites and their Spectra.

Brenner, Leo. Observations de Saturne. Bull. Soc. Astr. France 326–327, August 1897.

Campbell, W. W. Review of Mr. Lowell's Book on Mars. Pub. A. S. P. **8**, 207–220, 1896.

Campbell, W. W. Recent Observations of the Spectrum of Mars. Pub. A. S. P. **9**, 109–112, 1897.

Douglass, A. E. Nuages sur Mars. Bull. Soc. Astr. France, 290–292, July 1897.

Fontséré, Eduardo. Observations de Venus. Bull. Soc. Astr. France, 324–325. August 1897.

Griffiths, Henry F. La Planète Mars durant la dernière opposition. Bull. Soc. Belge d'Astr. **2**, 178, 1897.

Moye, M. Jupiter en 1897. Bull. Soc. Belge d'Astr. **2**, 215–216, 1897.

Peyra, D. Note sopra Marte Opposizione, 1896–7. Mem. Spettr. Ital. **26**, 61–64, 1897.

Pickering, W. H. La Météorologie de Mars. Bull. Soc. Belge d'Astr. **2**, 221–224, 1897.

Quenisset, F. Observations de Jupiter. Bull. Soc. Ast. France, 318–323, August 1897.

6. Comets, Meteors and their Spectra.

Barone, G. Les Bielides de 1895. Bull. Soc. Belge d'Astr. **2**, 207–209, 1897.

Editor Bull. Soc. Astr. France. Étoiles filantes d'août 1896. Bull. Soc. Astr. France, 328–329, August 1897.

Herschel, A. S. Bolides des 23 décembre 1895 et 16 decembre 1896. Bull. Soc. Astr. France, 292–294, July 1897.

7. Nebulæ and their Spectra.

Roberts, Isaac. Photograph of the Nebula Herschel V 14 Cygni Knowledge **20**, 218, 1897.

Scheiner, J. Spectroscopic Observations of Nebulæ made at Mount Hamilton by J. E. Keeler (Review). V. J. S. Astr. Gesell. **32**, 42–52, 1897.

Swift, Lewis. Catalogue No. 1 of Nebulæ Discovered at the Lowe Observatory, California. Pub. A. S. P. **9**, 301–306, 1896.

8. Terrestrial Physics.

Bauer, L. A. On the Distribution and the Secular Variation of Terrestrial Magnetism, No. IV. On the Component Fields of the Earth's Permanent Magnetism. Terr. Mag. **1**, 169–175, 1896.

Editor Terrestrial Magnetism. Note: The Elementary Pulsations of the Earth's Magnetism. Terr. Mag. **2**, 84, 1897.

Fleming, J. A. The Earth, a Great Magnet. Terr. Mag. **2**, 45–60, 1897.

Scheiner, J. Die Helmholtzschen Untersuchungen über Bewegungsvorgänge in unserer Atmosphäre. Himmel und Erde, **9**, 433–451, 1897.

de Tillo, A. Isanomales et variations séculaires des composantes Y et Z de la force magnétique horizontale pour l'époque 1857. Terr. Mag. **1**, 163–168, 1896.

9. Experimental and Theoretical Physics.

Ames, J. S. and W. J. Humphreys. Note on the Effect of Pressure upon the Series in the Spectrum of an Element. Johns Hopkins University Circulars, June 1897, Phil. Mag. **44**, 119 121, 1897.

Anderson, A. On the maximum deviation of a ray of light by a prism. Proc. Cambridge Phil. Soc, **9**, 195–197, 1896.

Arnold. W. Ueber Luminescenz. Wied. Ann. **61**, 314–329, 1897.

Cusack, Ralph. Effect of Change of Temperature on Phosphorescent Substances. Nat. **56**, 102, 1897.

Décombe, L. Sur la résonance multiple des ondulations électriques. Arch. de Genève, **4**, 30–38, 1897.

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Larmor, J. On the absolute Minimum of Optical Deviation by a Prism. Proc. Cambridge Phil. Soc. **9**, 108 110, 1896.

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Perrin, Jean. Décharge par les rayons X; influence de la pression et de la température. Séances Soc. Franc. Phys. 288, 1896.

Preston, Thomas. On a Supposed Proof of a Theorem in Wave-Motion. Phil. Mag, **43**, 458–460, 1897.

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THIELE, T. N. On the Law of Spectral Series. Ap. J. **6**, 65–76, 1897.

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WIND, C. H. Over den invloed van de af metingen der lichtbron by Fresnel'sche buigingsverschijnselen en over de buiging van X-stralen. Verslagen K. Akad. Wetens. Amsterdam, **6**, 79–84, 1897.

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10. THE SPECTRA OF THE ELEMENTS.

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LOHSE, O. Investigation of the Violet Part of some Metallic Spectra which Contain many Lines. Ap. J. **6**, 95–118, 1897.

11. PHOTOGRAPHY.

LIPPMANN, GABRIEL. La Photographie des couleurs. Bull. Soc. Astr. France, 280–283, July 1897.

LIVEING. On Photographing the whole length of a Spectrum at once. Proc. Cambridge Phil. Soc. **9**, 141–142, 1896.

NAEGAMVALA, K. D. On a Method of Reproducing Astronomical Photographs. Nat. **56**, 153, 1897.

WADSWORTH, F. L. O. Astronomical Photography. I. The Conditions which Determine the Limiting Time of Exposure. Knowledge. **20**, 193–195, 1897.

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WADSWORTH, F. L. O. On the Conditions of Maximum Efficiency in Astrophotographic Work. Part I.—General Theory of the Telescopic Image of Different Forms of Radiating Sources. Ap. J. **6**, 119–135, 1897.

12. INSTRUMENTS AND APPARATUS.

GUMLICH, E. Ueber die Herstellung von Aronsschen Bogenlampen mit Amalgamfüllung. Z. fur Instrum. **17**, 161–165; Wied. Ann. **61**. 401–407, 1897.

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13. GENERAL ARTICLES.

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HALE, GEORGE E. The Yerkes Observatory of the University of Chicago, Bulletin No. 2. Ap. J. **6**, 147–153, 1897.

HAGEN, J. G. A New Observatory. (Valkenburg, Holland.) Pub. A. S. P. **9**, 121–123, 1897.

JANSSEN, M. Progres de l'astronomie en 1896. Bull. Soc. Astr. France, 269–279, July 1897.

KEELER, JAMES E. On the Mode of Printing Maps of Spectra and Tables of Wave-Lengths. Ap. J. **6**, 144–146, 1897.

LOEWY, M. Rapport sur les Observatoires Astronomiques de Province, Année 1895.

WADSWORTH, F. L. O. Die Gravitations Constante, die Masse und Mittlere Dichte der Erde, von Dr. Carl Braun. (Review.) Ap. J. **6**, 159–163, 1897.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.*

THE

ASTROPHYSICAL JOURNAL

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THE IMPORTANCE OF ASTROPHYSICAL RESEARCH AND THE RELATION OF ASTROPHYSICS TO OTHER PHYSICAL SCIENCES.[1]

By James E. Keeler.

The domains of the physical sciences are not, like the political divisions represented on a map, capable of being defined by boundary lines traced with mathematical precision. They pass into one another by imperceptible gradations, the unity of nature opposing itself to rigid systems of classification. Thus there often exists between two allied sciences a broad ground, belonging to each, yet exclusively the property of neither, which may be so extensive and fertile as to justify the development of a new science for its special cultivation. And such a science not only subserves the purpose for which it was created, but it has the further special importance that, by promoting an exchange of knowledge between its previously established neighbors, by investigating the cause of disagreements between them, by comparing their methods, and possibly by detecting errors in their results, it tends to bring them into more perfect coördination.

Such is the nature of the science which Professor Langley has called the new astronomy, and which is also, and perhaps more generally, known as astrophysics. Its high development

[1] Address delivered at the dedication of the Verkes Observatory, Oct. 21, 1897.

has in fact been so recent that its name is found in only our latest dictionaries. It is closely allied on the one hand to astronomy, of which it may properly be classed as a branch, and on the other hand to chemistry and physics; but it assumes wide privileges, and it is ready to draw material which it can use with profit from any source, however distant. It seeks to ascertain the nature of the heavenly bodies, rather than their positions or motions in space—*what* they are, rather than *where* they are; and for my own convenience I shall use the terms astrophysics and astronomy to denote the sciences of which these aims are respectively characteristic. Yet here again the line of demarcation cannot be sharply drawn, since the measurement of celestial motions that cannot be dealt with by the methods of the older astronomy is one of the most important tasks of the astrophysicist. That which is perhaps most characteristic of astrophysics is the special prominence which it gives to the study of radiation. The complex nature of white light, in particular, is never lost sight of, and its consequences are thoroughly exploited.

That the older astronomers made no efforts systematically to study the nature of the heavenly bodies, is to be ascribed to the seeming hopelessness of such an attempt in their day, rather than to a lack of interest in the subject, or a slight appreciation of its importance on their part. They did in fact seek explanations of such phenomena as they could observe, and the beginnings of astrophysics are to be found far back in the past. But the curious speculations of Sir John Herschel on the structure of the Sun's photosphere show how inadequate was the supply of facts to serve as a basis for a science of solar physics in Herschel's time. The conception of living organisms a thousand miles long, floating about on the Sun's surface, and shining with the intense brilliancy of the photosphere, seems to us extraordinary, and even grotesque. To lose its strangeness it has to be considered with reference to the contemporary state of knowledge. But the fact that only fifty years ago it was regarded as an admissible supposition by one of the most eminent of astronomers helps us to realize how rapid has been the advance of

astrophysical science. It was only after the discovery was made, that the light which reveals to us the existence of the heavenly bodies also bears the secret of their constitution and physical condition, that the basis for a real science was obtained. The spectroscope placed new and hitherto undreamed of powers in the hands of men. It is to the astrophysicist what the graduated circle and the telescope are to the astronomer.

The study of astrophysics does not at present seem to have a very direct bearing on the practical affairs of everyday life. If to this statement the objection should be raised that the study of solar radiation is likely to lead to a practical method of utilizing the Sun's heat as a source of mechanical power, I should say that such a discovery (if it is ever made), is much more likely to be the result of an ingenious application of principles already known. What the future may have in store we cannot tell, but at present the statement I have made holds good. With respect to practical usefulness, therefore, astrophysics does not possess the same claims to consideration as astronomy, which has obviously important applications in furnishing standards of time, and in surveying, geodesy and navigation, and in addition to these, an immense indirect influence on thousands of ordinary affairs. Yet on such grounds it is not probable that any astronomer would care to base a claim for his science. Astronomy long ago reached that state of perfection which suffices for the practical ends I have mentioned, and is still pursued with undiminished vigor. Both astronomy and astrophysics take their stand on a higher plane, where it is a sufficient justification for their existence that they enable us better to understand the universe of which we form a part, and that they elevate the thoughts and ennoble the minds of men.

In considering the importance of astrophysical research I have, therefore, regarded the question from a purely scientific standpoint. Even with this restriction there is room for a considerable diversity of opinion, since the elimination of the human element from the question is impossible. Scientists are men. Every man is naturally inclined to attach special importance to

that in which he is himself specially interested. Personal preferences, or even prejudices, may enter into the estimation in which a branch of learning is held. But setting these aside, there are grounds for differences of opinion which are entitled to respect. What importance is to be attached, for example, to the proof, now brought almost within our grasp by the improvement of spectroscopic instruments and methods, that the law of gravity is operative within the stellar systems, as well as in the system of our own Sun? Doubtless there are some who are satisfied with the moral certainty that we already possess, and to whom the proof just mentioned would merely afford the satisfaction of inking in, on a printed form, the penciled words which had already been written in its blanks; while there are others who would regard the formal proof alone as entitled to consideration. I have even heard widely different opinions expressed by eminent astronomers as to the scientific importance of a problem so fundamental as the exact determination of the distance of the Sun.

The degree of importance which we attach to a newly discovered fact or principle is influenced by many circumstances, among which we cannot fail to recognize some of the failings of human nature. When progress is rapid, individual achievements lose their prominence, like mountain peaks rising from a high plateau. The discovery of an asteroid was once a notable event. Now it attracts little attention, outside of a small circle of observers, and it is probable that few of us could say just how many of these little bodies have been brought to light during the past year. In astrophysics discoveries of the highest significance have succeeded one another so rapidly that they are now taken as a matter of course.

The bearings of a discovery on existing knowledge are sometimes not immediately perceived, and its true scientific importance is not appreciated until these are revealed in the fullness of time. Other circumstances might be mentioned, but these are sufficient for my purpose — which is to show that there is no cause for surprise if opinions differ as to the exact value of

astrophysical research. It is because the science of astrophysics is so young — so distinctly in the formative stage — that I have ventured to discuss a question which, in due time, will settle itself.

A feature of astrophysical research which I do not wish to leave unmentioned is the interest which is felt in it by the public. Those who are interested in the results of science, but who care little for methods, and know nothing of elegant forms of analysis, are naturally more attracted by the view of the heavenly bodies which astrophysics presents, than by the view which is obtained from the standpoint of the older astronomy. Astrophysics paints its picture in the brighter colors. A star, regarded as a center of attraction, or as reference point from which to measure celestial motions, awakens little enthusiasm in the popular mind; but a star regarded as a sun, pouring out floods of light and heat as a consequence of its own contraction, torn by conflicting currents and fiery eruptions, shrouded in absorbing vapors or perhaps in vast masses of flame, appeals at once to the popular imagination. Both branches of astronomy share in the advantages which follow this awakening of popular interest; for that popular interest in any science is to be deprecated is, to my mind, utterly inadmissible. The cultivation of a pure science is possible only in those communities where such an intelligent interest exists. Without it we should not be here today. It is splendidly manifest around us. The only possible danger to be feared is, that interest in results whose significance is readily understood may lead to an undervaluation by the public of results which are of the highest importance, but which only the trained specialist can fully comprehend; and this danger will be avoided if scientific men publicly express their own appreciation of results which belong to the latter class.

Popular interest which is not of this character, but which has no purpose other than amusement, is less desirable. "It is the universal law," says Macaulay, "that whatever pursuit, whatever doctrine becomes fashionable, shall lose a portion of that dignity which it had possessed while it was confined to a small but earn-

est minority, and was loved for its own sake alone." Macaulay is here referring to a temporary interest in scientific matters which prevailed among fashionable circles in the reign of Charles the Second — to what would now be called a "fad." In our own time science occasionally suffers in much the same way. It is to be regretted that the habitability of the planets, a subject of which astronomers profess to know little, has been chosen as a theme for exploitation by the romancer, to whom the step from habitability to inhabitants is a very short one. The result of his ingenuity is that fact and fancy become inextricably tangled in the mind of the layman, who learns to regard communication with the inhabitants of Mars as a project deserving serious consideration (for which he may even wish to give money to scientific societies), and who does not know that it is condemned as a vagary by the very men whose labors have excited the imagination of the novelist. When he is made to understand the true state of our knowledge of these subjects he is much disappointed, and feels a certain resentment toward science, as if it had imposed upon him.

Science is not responsible for these erroneous ideas which, having no solid basis, gradually die out and are forgotten. Thus it cannot long suffer from outside misapprehension, while the sustained effort necessary to real progress is, in the end, a sufficient safeguard against the intrusion of triflers into its workshops.

In astrophysics sustained effort is as necessary as it is in other branches of science. There is an impression in some quarters that the results of astrophysical investigation are easily obtained. That this is in some cases true may readily be admitted. I cannot regard it as a reproach. It is one of the advantages, to which I have referred, of bringing new methods to bear on old problems. What an effort to grasp something tangible we observe in the earlier writing on Fermat's principle! What a groping in the dark after a principle felt rather than seen! And how obvious the same principle is from the standpoint of the wave theory! In a field so wide and so little explored as astrophysics, there must be novelties which can be gathered

with comparatively little effort, and which may nevertheless be of no small importance. But there are also problems whose solution calls for the exercise of the highest intellectual faculties, and for the most strenuous exertion.

In astrophysics difficulties are met with quite different from those of physical astronomy. There a vast variety of highly complex phenomena are to be referred to the operation of a well-known and extremely simple law. The mental discipline there obtained is of the highest order, and it is hardly necessary to say that a training in the methods of the older astronomy should be regarded as an indispensable preparation for astrophysical work. But in astrophysics, as in the sciences of chemistry and biology, there are difficulties which arise from an imperfect knowledge of the laws governing the phenomena observed. The discovery of unknown laws and principles, as well as the explanation of phenomena by laws already known, is one of its most important objects.

I have referred to the differences of opinion which usually exist, with reference to the value of a new science. There may be some who view with disfavor the array of chemical, physical, and electrical appliances crowded around the modern telescope, and who look back to the observatory of the past as to a classic temple whose severe beauty had not yet been marred by modern trappings. So mankind, dissatisfied with present social conditions, looks back with tender regret to the good old times of earlier generations, yet rushes forward with the utmost speed. May we regard the eagerness of pursuit as a measure of the value of its object? That the importance of astrophysical research, considered with respect both to its own ends and to its bearing on the advance of knowledge in other fields, is already great, and that it will grow steadily from year to year, is naturally my own belief. In a general way I have considered some of the reasons on which it is founded, and I now wish to call your attention to a few specific cases, which illustrate my general remarks, and in which I think the importance of astrophysical science is manifest.

Some of the most noteworthy advances in astronomy and in astrophysics have been made possible by the introduction of photography. The photographic plate not only gives a permanent record of what the eye can see, but, by its integrating power continued through long exposures, it builds up a picture from light impulses too feeble to affect the sense of vision. Thus it has been discovered that vast regions in the sky are filled with diffuse nebulæ, which (since the apparent brightness of a surface cannot be increased by any optical device) must ever remain unseen. This information, which the photographic plate alone could furnish, is itself most wonderful and suggestive. It is however but a part of what the same plate may yield. Whoever has studied Professor Barnard's admirable pictures of the Milky Way in Scorpio must have observed how accurately the distribution of the smallest stars corresponds to that of the extended nebulosity which fills this part of the sky, and at the same time how strikingly the nebulous matter is concentrated around the brightest stars in the constellation. Bright stars, faint stars, and nebulosity are unmistakably physically related, and hence at the same order of distance from the Earth; and from this it follows that the real sizes of the stars are of entirely different orders. Here is a fact having a most important bearing on the question of stellar distribution, brought out by the simplest possible means. It is perhaps beyond the reach of more elaborate methods. And in this case it is to be observed that the evidence would not be made clearer by any further treatment of the material. The positions of the stars and the density of the nebulosity might be measured, and the results might be tabulated, but all to no purpose; for, if the data yielded by observation were in the form of measurements, the first step toward their interpretation would be the construction of just such a chart as the photograph places ready in our hands.

Of very great importance to the new astronomy has been the investigation of the conditions of maximum efficiency of its chief instrument, the spectroscope, by the methods of physical

optics. The theory of resolving power, introduced by Lord Rayleigh, and quite recently elaborated by Professor Wadsworth, has been especially fruitful. It has done away with the old idea that the efficiency of a spectroscope is measured by its dispersion, and may be trusted to destroy in time some musty traditions concerning the magnifying power and definition of astronomical telescopes. The theory has also been extended so as to include the spectrograph, in which the photographic plate takes the place of the eye at the observing telescope of the spectroscope. The designing of spectroscopes has thus been placed on a thoroughly scientific basis. At the same time the demands for accuracy in the practical construction of the instrument have been greatly raised. The objectives, the prisms, the fitting of the mechanical parts must be the best possible. Hence the spectroscope has become an instrument of precision, worthy of a place among the most refined instruments of practical astronomy, and fitted for the class of work now most needed in astrophysical research.

A familiar example of the mutual obligations of allied sciences is found in the first measurements of the velocity of light. Perhaps a somewhat parallel case may have to be recorded by the future historian of science. Spectroscopists have tested the validity of what is known as Doppler's principle, by which the motion of a body in the line of sight is determined from the observed displacement of its spectral lines, and have at the same time proved the capabilities of their instruments, by means of the velocities of the Earth and heavenly bodies furnished to them by astronomy. It is not impossible that this also is a reversible process, and that measurements of the velocities of bodies in the solar system may give one of the best methods of determining the dimensions of their orbits.

Numerous cases could be mentioned in which astrophysical investigations have contributed to our knowledge of the chemical elements. Of these the first which naturally presents itself is one of the most recent. The element helium was discovered first in the Sun (as its name implies), then in the stars, then in

the nebulæ, and at last, by Professor Ramsay, it was "run to earth." It had an important place in celestial chemistry long before it was known to terrestrial science; and, on account of its rare occurrence and seeming inertness, it is quite possible that but for the spectroscope of the astrophysicist we should have remained forever ignorant of its existence. To the astrophysicist, however, it was known only by the occurrence in its spectrum of one bright line. Laboratory investigations soon revealed its complete spectrum, and then the astrophysicists were able to recognize, as belonging to helium, a large number of lines whose origin in the heavenly bodies they had been unable to discover. Our knowledge of the heavenly bodies may be greatly advanced when the properties of this remarkable element shall have been more thoroughly studied.

It is not necessary, however, to seek illustrations in new elements. The complete series of hydrogen lines, to which belong the few lines that are ordinarily seen in the laboratory spectroscope, was discovered by Huggins in the spectra of the white stars, and a new series, which had previously been seen by the eye of theory only, and which, so far as I know, has not yet been produced artificially, has recently been found by Pickering in the spectrum of the star Zeta Puppis.

Another familiar element is calcium. Its ordinary properties are well understood. But under the conditions met with in the Sun and stars it behaves in a mysterious manner. Notwithstanding its considerable atomic weight, it floats quietly high above the surface of the Sun, where other heavy metals are only occasionally present in consequence of violent eruptions. It is true that the apparently abnormal spectrum of calcium under these conditions has been shown by Sir William and Lady Huggins to be merely the result of extreme tenuity of the luminous vapor; but the existence of calcium at such great heights, under any conditions whatsoever, seems to point to some remarkable property of the element which is unrecognizable by the methods of ordinary chemistry.

The spectrum of a substance is not the same under all cir-

cumstances. In some cases a change occurs suddenly when certain critical conditions are reached; in others the change is gradual and progressive. By studying these changes in laboratory experiments, and comparing them with what we see in the observatory, we are able to arrive at some definite conclusions respecting the conditions which prevail in the stars, while the same comparison often throws light on the phenomena observed in the laboratory. It has been shown, for instance, that the spectrum of magnesium gives a means of estimating the temperatures of the stars; and the same criterion enables us to recognize in the stars temperatures vastly exceeding the highest that have been produced on the Earth. Thus the science of astrophysics allows us to extend our investigations to temperatures which the resources of the laboratory cannot furnish.

It may be well to mention an example of the difficulties, to which I have referred, arising from our imperfect knowledge of the laws which underlie phenomena constantly observed: Recent comparisons of the spectra of the Sun and metals, made at the Johns Hopkins University with the concave grating spectroscope of Professor Rowland, have proved that spectral lines may not merely be widened by increased pressure of the radiating vapor, but that they may be shifted bodily; while the still more recent investigations of Zeeman show that a line may be widened (and at the same time doubled) under the influence of a strong magnetic field. It is true that in both cases the effect produced is very small. It could not lead to mistakes in identifying stellar lines, or to appreciable errors in measuring celestial motions. But the fact that the spectrum of a substance varies according to circumstances which are as yet only imperfectly understood, shows us the necessity of exercising caution in interpreting the spectral phenomena presented to us by the heavenly bodies. At present these spectral variations increase the difficulties that the astrophysicist has to contend with. Eventually they will become additional and most valuable sources of information.

The discovery by Kayser and Runge of line series in the spectra of the common elements has a most important bearing

on the work of the astrophysicist. It provides him with the means, long greatly needed, of deciding with certainty whether or not lines in celestial spectra are identical with lines in the spectra of terrestrial substances. On the other hand, as we have already seen, he is sometimes able to supply the physicist with missing data.

From the standpoint of the older astronomy, the most important result of the introduction of new methods has been the determination of motions in the line of sight by means of the spectroscope. The method has been tested so often, and with such uniform success, that there is no longer any doubt as to the correctness of the principle on which it is based, or to the accuracy of the results which it is capable of yielding in competent hands. It is directly applicable to one of the great problems of astronomy — the determination of the direction and rate of the Sun's drift through space. From the proper motions of the stars, furnished by the methods of the older astronomy, the direction of the Sun's motion can be deduced, and, under certain assumptions as to the stars' distances, the rate of motion; but it is evident that the latter element of the problem must be subject to very considerable uncertainty. With the spectroscope velocities are directly measured, in miles per second. The two methods may be combined. It is probable that the most accurate determination of the *direction* of the Sun's drift can be obtained by comparing proper motions, while the most accurate value of the *velocity* is that given by the spectroscope. Thus, by the coöperation of the two branches of astronomy, there is measured in space a base line of constantly increasing length, for a great sidereal triangulation. At present the material afforded by spectroscopic observation is not sufficient for this great work. The observations must be treated statistically, and statistical methods can be applied successfully to only a large mass of data. What is now needed, therefore, is observations of more stars — *i. e.*, fainter stars; and the German government is building a large telescope for the Observatory at Potsdam, where photography was first applied to this class of

observations, in order that the work may be continued. There is room, however, for the employment of other large telescopes in the same field. The multiplication of observations for this purpose is no more to be deprecated than the multiplication of observations for the exact determination of star places.

Solar physics, from which the wider science of astrophysics has been evolved, offers problems so numerous and so complicated that I cannot even mention them, still less enter into a discussion of their bearing on other branches of knowledge. And what can I possibly say of their importance? The Sun is to us the grandest of material objects. It is the source of practically all our light and heat; of practically all our mechanical power; absolutely the support of all our lives. What wonder that we seek for knowledge of its nature by all the ways that we can find! These ways are opened through astrophysical research. In few of the inquiries that I have referred to can the method of light analysis be dispensed with. In most of them it offers the only chance of success.

I have time to mention only one new method of solar research. The most notable contribution to solar physics within the last few years has been the invention of the spectroheliograph by Hale and Deslandres. With this instrument photographs of the Sun are taken by strictly monochromatic light, which may be chosen from any part of the spectrum. If the part selected is the middle of the K line, the picture essentially represents the distribution of calcium vapor on the disk of the Sun, and the presence of other elements is ignored. This is, in fact, the line usually chosen, partly on account of the conspicuous rôle played by calcium in solar phenomena, and partly for other reasons which it is not necessary to state. The possibilities of the method are obvious. By an ingenious modification of his instrument, Hale now photographs on a single plate the Sun covered with all its spots and faculæ, and surrounded by all its prominences; and all this is done in a few minutes, in daylight! Could the corona be added, the triumph would be complete;

but the corona yet remains unconquered in its stronghold, though the attack is being vigorously pushed.

No branch of observational astronomy seems to be in so backward a state as the representation of the surface features of the planets. Although the Moon has been photographed with splendid success, and the planets with results that are encouraging and suggestive, we still rely (in the case of the planets) on the old method of hand-drawing used by Galileo. The fallibility of the draftsman is well known. It has been illustrated again and again. Yet there seems to be a curious habit among some observers of regarding a drawing, when once made, as invested with high authority—as that of a standard established by legislative act. A photograph, if it could be made, would be free from the errors of the draftsman, and from a personality which is recognizable in all hand-drawings, and which, though it is scarcely to be classed as an error, it would be desirable to avoid. Here, then, is another opportunity for the new methods. There is no reason to suppose that it is impossible to obtain photographs of the planets which will show all that the eye can see, although there are many reasons to know that it will be very difficult to do so. The instruments for this purpose would have to be quite different from those in general use, and there would be few occasions, in even the most favored regions of the Earth, when they could be employed. Difficulties would also arise from the rapid rotation of some of the planets. But this is not the place to discuss the necessary conditions. It is only fair to say that Professor Schaeberle, of the Lick Observatory, has already been experimenting in this direction—with what success is not yet generally known.

Passing to stellar spectroscopy, a field broader even than that of solar physics is opened before us, for the Sun, although paramount in his own system, is only one of the stars. In a general way, the spectra of the stars have been observed and classified according to their character, and objects of unusual interest have been noted for future investigation; many a rare specimen has been meshed in Harvard's widely extended net; but the detailed

study of individual spectra has just begun. For this purpose large telescopes are desirable, if not absolutely necessary. Many observations of precision required in the older astronomy are best made with small telescopes. But in stellar spectroscopy light is all-important, and while much can doubtless be accomplished with small telescopes, there is probably nothing that cannot be done better with large ones. Even in solar spectroscopy, where the supply of light is abundant, a large image is required for the study of individual parts of the Sun's surface.

No department of astrophysics has profited more by the introduction of photographic processes than stellar spectroscopy. To the advantages of photography already mentioned there is here to be added another not less important. Owing to atmospheric disturbances the image of a star dances about on the slit-plate of a spectroscope placed in the focus of a telescope. The spectrum is not only faint, but tremulous, and to measure the lines in it by visual observation is like trying to read a printed page irregularly illuminated by flashes of light. These irregularities do not appear on the photograph. They disappear in the process of integration. Negatives obtained with the spectrograph can be directly measured under a microscope, or enlargements can be made from them in the usual manner. In this way photographs of star spectra are now made which are comparable, with respect to accuracy and wealth of detail, to Kirchhoff's famous map of the solar spectrum. "It is simply amazing," says Professor Young, with reference to the Draper Memorial photographs, "that the feeble, twinkling light of a star can be made to produce such an autographic record of the substance and condition of the inconceivably distant luminary."

Let us consider for a moment some of the questions in this field that are open for investigation. The motions in the line of sight of all stars within reach of the largest telescopes have to be measured. This important line of research has already been referred to. The relation has to be ascertained between the various classes of star spectra and the probable order of stellar evolution. It now appears practically certain that all the stars

are not made according to a single pattern, and that they cannot be fitted into a single scheme of development. The Wolf-Rayet stars, the stars with banded spectra, the stars with bright-line spectra, the planetary nebulæ, the spectroscopic binaries, and the variable stars require the most careful attention. Variables of the Mira class should be followed with the spectroscope as far as possible from their maximum, and the spectral changes which accompany the light variation of other stars, whether due to phenomena of emission and absorption, or to relative motion of bodies in a revolving system, should be studied with the most powerful instruments.

The discovery by means of the spectroscope of binary stars which are far too close for resolution with our most powerful telescopes, and which are recognized in their true character by a periodic doubling of their spectral lines, has brought to our knowledge strange and wonderful conditions of orbital motion. Such a system as that of Spica, where two bodies like our Sun revolve around each other like the balls of a gigantic pendulum, in a period of only four days, at a distance no greater than that which separates the sixth satellite of Saturn from its primary, must have remained forever unknown to the older astronomy. Between these spectroscopic binaries and the most rapidly revolving doubles visible in the telescope there is a wide gap, the cause of which is obvious. The conditions favorable to discovery in the two cases are directly opposed, and doubtless a large class of stars lies at present just beyond the reach of either method.

But this gap may be bridged over by means of such a great telescope as we see before us today, while the work necessary to accomplish this end will open up still another field for research. It has long been recognized that the position micrometer and the spectroscope, taken together, are theoretically competent to determine the real orbits in space of the components of a double star; hence, also, the masses of the components, and their distance from the earth. Until recently the question had only a mathematical interest. But the small veloci-

ties to be expected in the case of any double star whose components can be separately distinguished with the telescope are now almost, if not quite, within reach of the spectroscope, and the investigation of such doubles has acquired a physical interest.

Here I must close my review of the important qvestions before the astrophysicist, with the consciousness that it is most remarkable for what it leaves unnoticed. I have said nothing of questions relating to the photography of comets and their spectra, the rotation of the planets or the absorption spectra of their atmospheres, the colors of double stars, the spectra of temporary stars, the measurement of obscure wave-lengths; nothing about stellar photometry, the application of interference methods to spectroscopic research, the exploration of the infra-red spectrum. But I will not trespass further on your patience. In all the fields that I have mentioned there are noble problems, worthy of the best efforts that can be given to their solution. To realize their importance think how ill we could spare what we have already won. What a blank would be left in our knowledge of the heavens if the results of astrophysical research in our own generation were stricken out!

The future should look bright indeed, as we view it today. Munificence and skill have provided this splendid Observatory with means for promoting knowledge in both the older and the newer branches of the sublime science to which it is dedicated. Its magnificent equipment will be used by men who have won merited distinction in both the older and the newer methods of research. It has the coöperation and support of a great institution of learning. From this happy union of ability and opportunity we have reason to expect results of the highest import to the new astronomy, and to its allied branches of physical science.

But, lest any words of mine should give rise to expectations that may not be fulfilled, I wish to say once more that important results are not necessarily of a striking or surprising character. We can hardly assume that every increase in telescopic power

will be followed by the discovery of new planets or satellites. Such discoveries, if they come, will be welcome; but they should not be expected. There may be no planets or satellites, yet undiscovered, in the solar system. But we may confidently expect from the work of this Observatory those results which throw light on the dark places in nature, and which, therefore, though they may not stimulate the popular imagination, are of the very highest importance, for they are indispensable to true scientific progress.

ASPECTS OF AMERICAN ASTRONOMY.[1]

By Simon Newcomb.

The University of Chicago yesterday accepted one of the most munificent gifts ever made for the promotion of any single science and with appropriate ceremonies dedicated it to the increase of our knowledge of the heavenly bodies.

The president of your university has done me the honor of inviting me to supplement what was said on that occasion by some remarks of a more general nature suggested by the celebration. One is naturally disposed to say first what is uppermost in his mind. At the present moment this will naturally be the general impression made by what has been seen and heard. The ceremonies were attended, not only by a remarkable delegation of citizens, but by a number of visiting astronomers, which seems large when we consider that the profession itself is not at all numerous in any country. As one of these, your guests, I am sure that I give expression only to their unanimous sentiment in saying that we have been extremely gratified in many ways by all that we have seen and heard. The mere fact of so munificent a gift to science cannot but excite universal admiration. We knew well enough that it was nothing more than might have been expected from the public spirit of this great West; but the first view of a towering snow peak is none the less impressive because you have learned in your geography how many feet high it is, and great acts are none the less admirable because they correspond to what you have heard and read, and might therefore be led to expect.

The next gratifying feature is the great public interest excited by the occasion. That the opening of a purely scientific institution should have led so large an assemblage of citizens to devote an entire day, including a long journey by rail,

[1] Address delivered at the University of Chicago, Oct. 22, 1897, in connection with the dedication of the Yerkes Observatory.

to the celebration of yesterday is something most suggestive from its unfamiliarity. A great many scientific establishments have been inaugurated during the last half century, but if on any such occasion so large a body of citizens has gone so great a distance to take part in the inauguration the fact has at the moment escaped from my mind.

That the interest thus shown is not confined to the hundreds of attendants, but must be shared by your great public, is shown by the unfailing barometer of journalism. Here we have a field in which the nonsurvival of the unfit is the rule in its most ruthless form; the journals that we see and read are merely the fortunate few of a countless number, dead and forgotten, that did not know what the public wanted to read about. The eagerness shown by the representatives of your press in recording everthing your guests would say was accomplished by an enterprise in making known everything that occurred and, in case of an emergency requiring a heroic measure, what did not occur, showing that smart journalists of the East must have learned their trade, or at least breathed their inspiration in these regions. I think it was some twenty years since I told a European friend that the eighth wonder of the world was a Chicago daily newspaper. Since that time the course of journalistic enterprise has been in the reverse direction, to that of the course of empire eastward, instead of westward.

It has been sometimes said — wrongfully I think — that scientific men form a mutual admiration society. One feature of the occasion made me feel that we, your guests, ought then and there to have organized such a society, and forthwith proceeded to business — this feature consisted in the conferences on almost every branch of astronomy by which the celebration of yesterday was preceded. The fact that beyond the acceptance of a graceful compliment I contributed nothing to these conferences relieves me from the charge of bias or self-assertion in saying that they gave me a new and most inspiring view of the energy now being expended in research by the younger generation of astronomers. All the experience of the past leads us to believe

that this energy will reap the reward which nature always bestows upon those who seek her acquaintance from unselfish motives. In one way it might appear that little was to be learned from a meeting like that of the present week—each astronomer may know by publications pertaining to the science what all the others are doing. But knowledge, obtained in this way, has a sort of abstractness about it a little like our knowledge of the progress of civilization in Japan, or of the great extent of the Australian continent. It was, therefore, a most happy thought on the part of your authorities to bring together the largest possible number of visiting astronomers from Europe as well as America, in order that each might see, through the attrition of personal contact, what progress the others were making in their researches. To the visitors at least I am sure that the result of this meeting has been extremely gratifying. They earnestly hope, one and all, that the callers of the conference will not themselves be more disappointed in its results; that however little they may have actually to learn of methods and results, they will feel stimulated to well directed efforts and find themselves inspired by thoughts which, however familiar, will now be more easily worked out.

We may pass from the aspects of the case as seen by the strictly professional class to those general aspects fitted to excite the attention of the great public. From the point of view of the latter it may well appear that the most striking feature of the celebration is the great amount of effort which it shows to be devoted to the cultivation of a field quite outside the ordinary range of human interests.

A little more than two centuries ago Huyghens prefaced an account of his discoveries on the planet Saturn with the remark that many, even among the learned, might think he had been devoting to things too distant to interest mankind an amount of study which would better have been devoted to subjects of more immediate concern. It must be admitted that this fear has not deterred succeeding astronomers from pursuing their studies. The enthusiastic students whom we see around

us are only a detachment from an army of investigators who, in many parts of the world, are seeking to explore the mysteries of creation. Why so great an expenditure of energy? Certainly not to gain wealth, for astronomy is perhaps the one field of scientific work which, in our expressive modern phrase, "has no money in it." It is true that the great practical use of astronomical science to the country and the world in affording us the means of determining positions on land and at sea is frequently pointed out. It is said that an Astronomer Royal of England once calculated that every meridian observation of the Moon made at Greenwich was worth a pound sterling, on account of the help it would afford to the navigation of the ocean. An accurate map of the United States cannot be constructed without astronomical observations at numerous points scattered over the whole country, aided by data which great observatories have been accumulating for more than a century, and must continue to accumulate in the future.

But neither the measurement of the Earth, the making of maps, nor the aid of the navigator is the main object which the astronomers of today have in view. If they do not quite share the sentiment of that eminent mathematician, who is said to have thanked God that his science was one which could not be prostituted to any useful purpose, they still know well that to keep utilitarian objects in view would only prove a handicap on their efforts. Consequently, they never ask in what way their science is going to benefit mankind.

As the great captain of industry is moved by the love of wealth, and the politician by the love of power, so the astronomer is moved by the love of knowledge for its own sake, and not for the sake of its application. Yet he is proud to know that his science has been worth more to mankind than it has cost. He does not value its results merely as a means of crossing the ocean or mapping the country, for he feels that man does not live by bread alone. If it is not more than bread to know the place we occupy in the universe, it is certainly something which we should place not far behind the means of subsistence. That we now

look upon a comet as something very interesting, of which the sight affords us a pleasure unmixed with fear of war, pestilence, or other calamity, and of which we therefore wish the return, is a gain we cannot measure by money. In all ages astronomy has been an index to the civilization of the people who cultivated it. It has been crude or exact, enlightened or mingled with superstition, according to the current mode of thought. When once men understand the relation of the planet on which they dwell to the universe at large, superstition is doomed to speedy extinction. This alone is an object worth more than money.

Astronomy may fairly claim to be that science which transcends all others in its demands upon the practical application of our reasoning powers. Look at the stars that stud the heavens on a clear evening. What more hopeless problem to one confined to earth than that of determining their varying distances, their motions, and their physical constitution? Everything on earth we can handle and investigate. But how investigate that which is ever beyond our reach, on which we can never make an experiment? On certain occasions we see the Moon pass in front of the Sun and hide it from our eyes. To an observer a few miles away the Sun was not entirely hidden, for the shadow of the Moon in a total eclipse is rarely one hundred miles wide. On another continent no eclipse at all may have been visible. Who shall take a map of the world and mark upon it the line on which the Moon's shadow will travel during some eclipse a hundred years hence? Who shall map out the orbits of the heavenly bodies as they are going to appear in a hundred thousand years? How shall we ever know of what chemical elements the Sun and the stars are made? All this has been done, but not by the intellect of any one man. The road to the stars has been opened only by the efforts of many generations of mathematicians and observers, each of whom began where his predecessor had left off. We have reached a certain stage where we know much about the heavenly bodies.

We have mapped out our solar system with great precision. But how with that great universe of millions of stars in which

our solar system is only a speck of star dust, a speck which a traveler through the wilds of space might pass a hundred times without notice? We have learned much about this universe, though our knowledge of it is still dim. We see it as a traveler on a mountain top sees a distant city in a cloud of mist, by a few specks of glimmering light from steeples or roofs. We want to know more about it, its origin and its destiny; its limits in time and space, if it has any; what function it serves in the universal economy. The journey is long, yet we want, in knowledge at least, to reach the stars. Hence we build observatories and train observers and investigators. Slow indeed is progress in the solution of the greatest of problems, when measured by what we want to know. Some questions may require centuries, others thousands of years for their answer. And yet never was progress more rapid than during our time. In some directions our astronomers of today are out of sight of those of fifty years ago; we are even gaining heights which, twenty years ago, looked hopeless. Never before had the astronomer so much work, good, hard, yet hopeful work before him as today. He who is leaving the stage feels that he has only begun, and must leave his successors with more to do than his predecessors left him.

To us an interesting feature of this progress is the part taken in it by our own country. The science of our day, it is true, is of no country. Yet we very appropriately speak of American science from the fact that our traditional reputation has not been that of a people deeply interested in the higher branches of intellectual work. Men yet living can remember when in the eyes of the universal church of learning all cisatlantic countries, our own included, were *partes infidelium.*

Yet American astronomy is not entirely of our generation. In the middle of the last century Professor Winthrop, of Harvard, was an industrious observer of eclipses and kindred phenomena, whose work was recorded in the transactions of learned societies. But the greatest astronomical activity during our colonial period was that called out by the transit of Venus in 1769, which was visible in this country. A committee of the

American Philosophical Society, at Philadelphia, organized an excellent system of observations, which we now know to have been fully as successful, perhaps more so, than the majority of those made on other continents, owing mainly to the advantages of air and climate. Among the observers was the celebrated Rittenhouse, to whom is due the distinction of having been the first American astronomer whose work has an important place in the history of the science. In addition to the observations which he has left us, he was the first inventor or proposer of the collimating telescope, an instrument which has become almost a necessity wherever accurate observations are made. The fact that the subsequent invention by Bessel was quite independent, does not detract from the merits of either.

Shortly after the transit of Venus, which I have mentioned, the War of the Revolution commenced. The generation which carried on that war, and the following one which formed our constitution and laid the bases of our political institutions, were naturally too much occupied with these great problems to pay much attention to pure science. While the great mathematical astronomers of Europe were laying the foundation of celestial mechanics their meetings were a sealed book to everyone on this side of the Atlantic, and so remained until Bowditch appeared, early in the present century. His translation of the *Mécanique Céleste* made an epoch in American science by bringing the great work of Laplace down to the reach of the best American students of his time.

American astronomers must always honor the names of Rittenhouse and Bowditch. And yet, in one respect, their work was disappointing of results. Neither of them was the founder of a school. Rittenhouse left no successor to carry on his work. The help which Bowditch afforded his generation was invaluable to isolated students who, here and there, dived alone and unaided into the mysteries of the celestial motions. His work was not mainly in the field of observational astronomy, and therefore did not materially influence that branch of the science. In 1832 Professor Airy, afterward Astronomer Royal of England, made a

report to the British Association on the condition of practical astronomy in various countries. In this report he remarked that he was unable to say anything about American astronomy because, so far as he knew, no public observatory existed in the United States.

William C. Bond, afterward famous as the first director of Harvard Observatory, was at that time making observations with a small telescope, first near Boston, and afterward at Cambridge. But with so meager an outfit, his establishment could scarcely lay claim to being an astronomical observatory, and it was not surprising if Airy did not know anything of his modest efforts.

If at this time Professor Airy had extended his investigations into yet another field, with a view of determining the prospects for a great city at the site of Fort Dearborn, on the southern shore of Lake Michigan, he would have seen as little prospect of civic growth in that region as of a great development of astronomy in the United States at large. A plat of the proposed town of Chicago had been prepared two years before, when the place contained perhaps half a dozen families. In the same month in which Professor Airy made his report, August 1832, the people of that place, then numbering twenty-eight voters, decided to become incorporated, and selected five trustees to carry on their government.

In 1837 a city charter was obtained from the legislature of Illinois. The growth of this infant city, then small even for an infant, into the great commercial metropolis of the West, has been the just pride of its people and the wonder of the world. I mention it now because of a remarkable coincidence. With this civic growth has quietly gone on another, little noted by the great world, and yet in its way equally wonderful and equally gratifying to the pride of those who measure greatness by intellectual progress. If it be true that in nature nothing is great but man; in man nothing is great but mind; then may knowledge of the universe be regarded as the true measure of progress. I therefore invite attention to the fact that American

astronomy began with your city, and has slowly but surely kept pace with it until today our country stands second only to Germany in the number of researches being prosecuted, and second to none in the number of men who have gained the highest recognition by their labors.

In 1836 Professor Albert Hopkins, of Williams College, and Professor Elias Loomis, of Western Reserve College, Ohio, both commenced little observatories. Professor Loomis went to Europe for all his instruments, but Hopkins was able even then to get some of his in this country. Shortly afterward a little wooden structure was erected by Captain Gilliss on Capitol Hill at Washington, and supplied with a transit instrument for observing Moon culminations in conjunction with Captain Wilkes, who was then setting out on his exploring expedition to the southern hemisphere. The date of these observatories was practically the same as that on which a charter for the city of Chicago was obtained from the legislature. With their establishment the population of your city had increased to 703.

The next decade, 1840 to 1850, was that in which our practical astronomy seriously commenced. The little observatory of Captain Gilliss was replaced by the Naval Observatory, erected at Washington during the years 1843–4 and fitted out with what were then the most approved instruments. About the same time the appearance of the great comet of 1843 led the citizens of Boston to erect the Observatory of Harvard College. Thus it is little more than a half century since the two principal observatories in the United States were established. But we must not for a moment suppose that the mere erection of an observatory can mark an epoch in scientific history. What must have made the decade of which I speak ever memorable in American astronomy was not merely the erection of buildings, but the character of the work done by astronomers away from them as well as in them.

The Naval Observatory very soon became famous by two remarkable steps which raised our country to an important position among those applying modern science to practical uses. One

of these consisted of the researches of Sears Cook Walker on the motion of the newly discovered planet Neptune. He was the first astronomer to determine fairly good elements of the orbit of that planet, and, what is yet more remarkable, he was able to trace back the movement of the planet in the heavens for half a century, and to show that it had been observed as a fixed star by Lalande in 1795, without the observer having any suspicion of the true character of the object.

The other work to which I refer was the application to astronomy and to the determination of longitudes of the chronographic method of registering transits of stars or other phenomena requiring an exact record of the instant of their occurrence. It is to be regretted that the history of this application has not been fully written. In some points there seems to be as much obscurity as with the discovery of ether as an anæsthetic, which took place about the same time. Happily no such contest has been fought over the astronomical as over the surgical discovery—the fact being that all who were engaged in the application of the new method were more anxious to perfect it than they were to get credit for themselves. We know that Saxton of the Coast Survey, Mitchell and Locke, of Cincinnati, Bond at Cambridge, as well as Walker and other astronomers at the Naval Observatory, all worked at the apparatus, that Maury seconded their efforts with untiring zeal, that it was used to determine the longitude of Baltimore as early as 1844 by Captain Wilkes, and that it was put into practical use in recording observations at the Naval Observatory as early as 1846.

At the Cambridge Observatory the two Bonds, father and son, speedily began to show the stuff of which the astronomer is made. A well-devised system of observations was put in operation. The discovery of the dark ring of Saturn and of a new satellite to that planet gave additional fame to the establishment.

Nor was activity confined to the observational side of the science. The same decade of which I speak was marked by the beginning of Professor Pierce's mathematical work, especially

his determination of the perturbations of Uranus and Neptune. At this time commenced the work of Dr. B. A. Gould, who soon became the leading figure in American astronomy. Immediately on graduating at Harvard in 1845, he determined to devote all the energies of his life to the prosecution of his favorite science. He studied in Europe for three years, took the doctor's degree at Göttingen, came home, founded the *Astronomical Journal*, and took an active part in that branch of the work of the Coast Survey which included the determination of longitudes by astronomical methods.

An episode which may not belong to the history of astronomy must be acknowledged to have had a powerful influence in exciting public interest in that science. Professor O. M. Mitchell, the founder and first director of the Cincinnati Observatory, made the masses of our intelligent people acquainted with the leading facts of astronomy by courses of lectures which, in lucidity and eloquence, have never been excelled. The immediate object of the lectures was to raise funds for establishing his observatory and fitting it out with a fine telescope. The popular interest thus excited in the science had an important effect in leading the public to support astronomical research. If public support, based on public interest, is what has made the present fabric of American astronomy possible, then should we honor the name of a man whose enthusiasm leavened the masses of his countrymen with interest in our science.

The Civil War naturally exerted a depressing influence upon our scientific activity. The cultivator of knowledge is no less patriotic than his fellow-citizens, and vies with them in devotion to the public welfare. The active interest which such cultivators took, first in the prosecution of the war and then in the restoration of the union, naturally distracted their attention from their favorite pursuits. But no sooner was political stability reached than a wave of intellectual activity set in, which has gone on increasing up to the present time. If it be true that never before in our history has so much attention been given to education as now; that never before did so many men devote

themselves to the diffusion of knowledge, it is no less true that never was astronomical work so energetically pursued among us as now.

One deplorable result of the Civil War was that Gould's *Astronomical Journal* had to be suspended. Shortly after the restoration of peace, instead of reëstablishing the journal, its founder conceived the project of exploring the southern heavens. The northern hemisphere being the seat of civilization, that portion of the sky which could not be seen from our latitudes was comparatively neglected. What had been done in the southern hemisphere was mostly the occasional work of individuals and of one or two permanent observatories. The latter were so few in number and so meager in their outfit that a splendid field was open to the inquirer. Gould found the patron which he desired in the government of the Argentine Republic, on whose territory he erected what must rank in the future as one of the memorable astronomical establishments of the world. His work affords a most striking example of the principle that the astronomer is more important than his instruments. Not only were the means at the command of the Argentine Observatory slender in the extreme when compared with those of the favored institutions of the North, but, from the very nature of the case, the Argentine Republic could not supply trained astronomers. The difficulties thus growing out of the administration cannot be overestimated. And yet the sixteen great volumes in which the work of the institution has been published will rank in the future among the classics of astronomy.

Another wonderful focus of activity, in which one hardly knows whether he ought most to admire the exhaustless energy or the admirable ingenuity which he finds displayed, is the Harvard Observatory. Its work has been aided by gifts which have no parallel in the liberality that prompted them. Yet without energy and skill such gifts would have been useless. The activity of the establishment includes both hemispheres. Time would fail to tell how it has not only mapped out important regions of the heavens from the north to the south pole, but

analyzed the rays of light which come from hundreds of thousands of stars by recording their spectra in permanence on photographic plates.

The work of the establishment is so organized that a new star cannot appear in any part of the heavens, nor a known star undergo any noteworthy change, without immediate detection by the photographic eye of one or more little telescopes, all seeing and never sleeping policemen, that scan the heavens unceasingly while the astronomer may sleep, and report in the morning every case of irregularity in the proceedings of the heavenly bodies.

Yet another example, showing what great results may be obtained with limited means is afforded by the Lick Observatory, on Mount Hamilton, California. During the ten years of its activity its astronomers have made it known the world over by works and discoveries too varied and numerous to be even mentioned at the moment.

The astronomical work of which I have thus far spoken has been almost entirely that done at observatories. I fear that I may in this way have strengthened an erroneous impression that the seat of important astronomical work is necessarily connected with an observatory. In must be admitted that an institution which has a local habitation and a magnificent building commands public attention so strongly that valuable work done elsewhere may be overlooked. A very important part of astronomical work is done away from telescopes and meridian circles, and requires nothing but a good library for its prosecution. One who is devoted to this side of the subject may often feel that the public does not appreciate his work at its true relative value, from the very fact that he has no great buildings or fine instruments to show. I may, therefore, be allowed to claim as an important factor in the American astronomy of the last half century an institution of which few have heard and which has been overlooked because there was nothing about it to excite attention.

In 1849 the *American Nautical Almanac* office was estab-

lished by a congressional appropriation. The title of this publication is somewhat misleading in suggesting a simple enlargement of the family almanac which the sailor is to hang up in his cabin for daily use. The fact is that what started more than a century ago as a nautical almanac has since grown into an astronomical ephemeris for the publication of everything pertaining to times, seasons, eclipses and the motions of the heavenly bodies. It is the work in which astronomical observations made in all the great observatories of the world are ultimately utilized for scientific and public purposes. Each of the leading nations of western Europe issues such a publication. When the preparation and publication of the American ephemeris was decided upon the office was first established in Cambridge, the seat of Harvard University, because there could most readily be secured the technical knowledge of mathematics and theoretical astronomy necessary for the work.

A field of activity was thus opened, of which a number of able young men who have since earned distinction in various walks of life availed themselves. The head of the office, Commander Davis, adopted a policy well fitted to promote their development. He translated the classic work of Gauss, *Theoria Motus Corporum Cœlestium*, and made the office a sort of informal school, not, indeed, of the modern type, but rather more like the classic grove of Hellas, where philosophers conducted their discussions and profited by mutual attrition. When, after a few years of experience, methods were well established and a routine adopted, the office was removed to Washington, where it has since remained. The work of preparing the ephemeris has, with experience, been reduced to a matter of routine which may be continued indefinitely, with occasional changes in methods and data and improvements to meet the increasing wants of investigators.

The mere preparation of the ephemeris includes but a small part of the work of mathematical calculation and investigation required in astronomy. One of the great wants of the science today is the re-reduction of the observations made during the

first half of the present century, and even during the last half of the preceding one. The labor which could profitably be devoted to this work would be more than that required in any one astronomical observatory. It is unfortunate for this work that a great building is not required for its prosecution because its needfulness is thus very generally overlooked by that portion of the public interested in the progress of science. An organization especially devoted to it is one of the scientific needs of our time.

In such an epoch-making age as the present it is dangerous to cite any one step as making a new epoch. Yet it may be that when the historian of the future reviews the science of our day he will find the most remarkable feature of the astronomy of the last twenty years of our century to be the discovery that this steadfast Earth of which the poets have told us is not after all quite steadfast; that the north and south poles move about a very little, describing curves so complicated that they have not yet been fully marked out. The periodic variations of latitude thus brought about were first suspected about 1880, and announced with some modest assurance by Küstner, of Berlin, a few years later. The progress of the views of astronomical opinion from incredulity to confidence was extremely slow until, about 1890, Chandler, of the United States, by an exhaustive discussion of innumerable results of observations showed that the latitude of every point on the Earth was subject to a double oscillation, one having a period of a year, the other of 427 days.

Notwithstanding the remarkable parallel between the growth of American astronomy and that of your city, one cannot but fear that if a foreign observer had been asked only half a dozen years ago at what point in the United States a great school of theoretical and practical astronomy, aided by an establishment for the exploration of the heavens, was likely to be established by the munificence of private citizens, he would have been wiser than most foreigners had he guessed Chicago. Had this place been suggested to him I fear he would have replied that were

it possible to utilize celestial knowledge in acquiring earthly wealth here would be the most promising seat for such a school. But he would need to have been a little wiser than his generation to reflect that wealth is at the base of all progress in knowledge and the liberal arts, that it is only when men are relieved from the necessity of devoting all their energies to the immediate wants of life that they can lead intellectual lives, and that we should therefore look to the most enterprising commercial center as the likeliest seat for a great scientific institution.

Now we have the school, and we have the Observatory, which we hope will in the near future do work that will cast luster on the name of its founder as well as on the astronomers who may be associated with it. You will, I am sure, pardon me if I make some suggestions on the subject of the future needs of the establishment. We want this newly founded institution to be a great success, to do work which shall show that the intellectual productiveness of your community will not be allowed to lag behind its material growth. The public is very apt to feel that when some munificent patron of science has mounted a great telescope under a suitable dome and supplied all the apparatus which the astronomer wants to use success is assured. But such is not the case. The most important requisite, one more difficult to command than telescopes or observatories, may still be wanting. A great telescope is of no use without a man at the end of it, and what the telescope may do depends more upon this appendage than upon the instrument itself. The place which telescopes and observatories have taken in astronomical history are by no means proportional to their dimensions. Many a great instrument has been a mere toy in the hands of its owner. Many a small one has become famous. Twenty years ago there was here in your own city a modest little instrument which, judged by its size, could not hold up its head with the great ones even of that day.

It was the private property of a young man holding no scientific position and scarcely known to the public. And yet that little telescope is today among the famous ones of the world,

having made memorable advances in the astronomy of double stars, and shown its owner to be a worthy successor of the Herschels and the Struves in that line of work. A hundred observers might have used the appliances of the Lick Observatory for a whole generation without finding the fifth satellite of Jupiter; without successfully photographing the cloud forms of the Milky Way; without discovering the extraordinary patches of nebulous light, nearly or quite invisible to the human eye, which fill some regions of the heavens.

When I was in Zurich last year I paid a visit to the little but not unknown observatory of its famous polytechnic school. The professor of astronomy was especially interested in the observations of the Sun with the aid of the spectroscope, and among the ingenious devices which he described, not the least interesting was the method of photographing the Sun by special rays of the spectrum which had been worked out at the Kenwood Observatory in Chicago. The Kenwood Observatory is not, I believe, in the eye of the public one of the noteworthy institutions of your city which every visitor is taken to see, and yet this invention has given it an important place in the science of our day.

Should you ask me what are the most hopeful features in the great establishment which you are now dedicating I would say that they are not alone to be found in the size of your unequaled telescope, nor in the cost of the outfit, but in the fact that your authorities have shown their appreciation of the requirements of success by adding to the material outfit of the establishment the three men whose works I have described.

Gentlemen of the trustees, allow me to commend to your fostering care the men at the end of the telescope. The constitution of the astronomer shows curious and interesting features. If he is destined to advance the science by works of real genius he must, like the poet, be born, not made. The born astronomer, when placed in command of a telescope, goes about using it as naturally and effectively as the babe avails itself of its mother's breast. He sees intuitively what less gifted men have to learn by long study and tedious experiment. He is moved

to celestial knowledge by a passion which dominates his nature. He can no more avoid doing astronomical work, whether in the line of observations or research, than the poet can chain his Pegasus to earth. I do not mean by this that education and training will be no use to him. They will certainly accelerate his early progress. If he is to become great on the mathematical side, not only must his genius have a bend in that direction, but he must have the means of pursuing his studies. And yet I have seen so many failures of men who had the best instruction, and so many successes of men who scarcely learned anything of their teachers, that I sometimes ask whether the great American celestial mechanician of the twentieth century will be a graduate of a university or of the backwoods.

Is the man thus moved to the exploration of nature by an unconquerable passion more to be envied or pitied? In no other pursuit does success come with such certainty to him who deserves it. No life is so enjoyable as that whose energies are devoted to following out the inborn impulses of one's nature. The investigator of truth is little subject to the disappointments which await the ambitous man in other fields of activity. It is pleasant to be one of a brotherhood extending over the world, in which no rivalry exists except that which comes out of trying to do better work than anyone else, while mutual admiration stifles jealousy. And yet, with all these advantages, the experience of the astronomer may have its dark side. As he sees his field widening faster than he can advance he is impressed with the littleness of all that can be done in one short life. He feels the same want of successors to pursue his work that the founder of a dynasty may feel for heirs to occupy his throne. He has no desire to figure in history as a Napoleon of science whose conquests must terminate with his life. Even during his active career his work may be of such a kind as to require the coöperation of others and the active support of the public. If he is disappointed in commanding these requirements, if he finds neither coöperation nor support, if some great scheme to which he may have devoted much of his life

thus proves to be only a castle in the air, he may feel that nature has dealt hardly with him in not endowing him with passions like to those of other men.

In treating a theme of perennial interest one naturally tries to fancy what the future may have in store. If the traveler contemplating the ruins of some ancient city which in the long ago teemed with the life and activities of generations of men sees every stone instinct with emotion and the dust alive with memories of the past, may he not be similarly impressed when he feels that he is looking around upon a seat of future empire; a region where generations yet unborn may take a leading part in molding the history of the world? What may we not expect of that energy which in sixty years has transformed a straggling village into one of the world's great centers of commerce? May it not exercise a powerful influence on the destiny not only of the country but of the world? If so, shall the power thus to be exercised prove an agent of beneficence, diffusing light and life among nations, or shall it be the opposite?

The time must come ere long when wealth shall outgrow the field in which it can be profitably employed. In what direction shall its possessors then look? Shall they train a posterity which will so use its power as to make the world better that it has lived in it? Will the future heir to great wealth prefer the intellectual life to the life of pleasure?

We can have no more hopeful answer to these questions than the establishment of this great University in the very focus of the commercial activity of the West. Its connection with the institution we have been dedicating suggests some thoughts on science as a factor in that scheme of education best adapted to make the power of a wealthy community a benefit to the race at large. When we see what a factor science has been in our present civilization, how it has transformed the world and increased the means of human enjoyment by enabling men to apply the powers of nature to their own uses, it is not wonderful that it should claim the place in education hitherto held by classical studies. In the contest which has thus arisen I take no part but

that of a peacemaker, holding that it is as important to us to keep in touch with the traditions of our race and to cherish the thoughts which have come down to us through the centuries as it is to enjoy and utilize what the present has to offer us. Speaking from this point of view, I would point out the error of making the utilitarian applications of knowledge the main object in its pursuit. It is a historic fact that abstract science, science pursued without any utilitarian end, has been at the basis of our progress in the application of knowledge. If in the last century such men as Galvani and Volta had been moved by any other motive than love of penetrating the secrets of nature they would never have pursued the seemingly useless experiments they did, and the foundation of electrical science would not have been laid. Our present applications of electricity did not become possible until Ohm's mathematical laws of the electric current, which when first made known seemed little more than mathematical curiosities, had become the common property of inventors. Professional pride on the part of our own Henry led him, after making the discoveries which rendered the telegraph possible, to go no further in their application, and to live and die without receiving a dollar of the millions which the country has won through his agency.

In the spirit of scientific progress thus shown, we have patriotism in its highest form: a sentiment which does not seek to benefit the country at the expense of the world, but to benefit the world by means of one's country. Science has its competition, as keen as that which is the life of commerce. But its rivalries are over the question who shall contribute the most and the best to the sum total of knowledge, who shall give the most, not who shall take the most. Its animating spirit is love of truth. Its pride is to do the greatest good to the greatest number. It embraces not only the whole human race but all nature in its scope. The public spirit of which this city is the focus has made the desert blossom as the rose, and benefited humanity by the diffusion of the material products of the earth. Should you ask me how it is in the future to use its influence for the

benefit of humanity at large, I would say, look at the work now going on in these precincts, and study its spirit. Here are the agencies which will make "the voice of law and harmony of the world." Here is the love of country blended with the love of the race. Here the love of knowledge is as unconfined as your commercial enterprise. Let not your youth come hither merely to learn the forms of vertebrates and the properties of oxides, but rather to imbibe that catholic spirit which, animating their ever gracious energies, shall make the power they shall wield "an agent of beneficence to all mankind.

THE AIM OF THE YERKES OBSERVATORY.[1]

By George E. Hale, Director.

It gives me very great pleasure to extend to you all, on behalf of the members of the staff of the Yerkes Observatory, a most cordial welcome. The feeling of satisfaction which I share with my colleagues at seeing so many present is deepened by the peculiar circumstances under which we have come together. Removed from the neighborhood of great cities, and from the more populous regions of the United States, the Yerkes Observatory could hardly have hoped to draw hither so many well-known investigators. Realizing as we do the great distances many of you have come to favor us with your presence today, we assure you of our high appreciation of the honor thus done to the Observatory. The season and the place alike render difficult the provision of such entertainment as we would wish to offer. But all that we have is placed freely at your disposal, in the hope that the week may not be without some element of pleasure or profit to every one who has come to take part in these conferences.

I am sure that those who have watched, with an interest not confined to a single field, the recent parallel advances of astronomy and physics, will feel a peculiar sense of satisfaction in our gathering today. The fact that the programme of the conferences has attracted hither not only astronomers whose researches deal with all phases of their subject, but also physicists, fresh from the investigations of the laboratory, will indicate my meaning. If I mistake not the signs of the times, the Yerkes Observatory can render no better service to both astronomy and physics than to contribute, in such degree as its resources may allow, toward strengthening the good will and common interest which are ever tending to draw astronomers and physicists into closer

[1] Address delivered at the conferences held in connection with the dedication of the Yerkes Observatory, Oct. 19, 1897.

touch. During its three years of publication, the ASTROPHYSICAL JOURNAL has had the same end in view. The annual meetings of its editors, of late devoted mainly to the informal discussion of astrophysical investigations, have invariably been of great interest and value. Both physical and astronomical subjects have been considered equally appropriate for presentation, and the privilege of listening to discussions in which both sides of a question received attention has been greatly valued by those who have taken part in the meetings. In the pages of the JOURNAL one is likely to find a paper on radiation in a magnetic field in close proximity to an account of nebular photography or a discussion of stellar motion in the line of sight. For the scope of astrophysical work is far from narrow. In considering it we must remember that the problems it offers may be viewed in two ways. He who is primarily an astronomer, when examining the photographic spectrum of some remarkable variable star, will be inclined to seek in the shifting dark and bright lines evidence of orbital motion, or indications that may lead to the discovery of the nature of the system. The physicist may find himself equally interested in the photograph, but in a different way. The peculiarities of the spectral lines may have to him the highest significance in connection with some of his own molecular studies. The special conditions of temperature or pressure needed to bring out certain series of lines, known through theoretical investigation perhaps, but not to be developed by any familiar laboratory process, may actually exist in the atmosphere of this distant star. To the physicist, and even to the chemist, this fiery crucible may afford the means of performing experiments far beyond the scope of terrestrial laboratories. In such a case the spectroscope might well be considered the essential instrument of research, the telescope playing a lesser, but nevertheless a very important rôle. It is sometimes interesting to remember that from certain points of view a telescope may not improperly be defined as an instrument for forming an image of a celestial object on the slit of a spectroscope.

Hydrogen gas affords a most interesting illustration of what has just been said. When first studied in the laboratory its spectrum showed four lines in the visible region, and none in the ultra-violet. Then came the pioneer work of Sir William Huggins in photographing the spectra of the stars. He at once found from investigations of Sirius and other white stars that the four bright lines represented only the first few terms of a beautiful rythmical series stretching far into the ultra-violet. The regularity of the grouping was such as to compel belief in the physical continuity of the series, in spite of the failure of the ultra-violet lines to make their appearance in the vacuum tube. Almost simultaneously with Sir William Huggins' discovery of the stellar series, the gas was made to emit these radiations in the laboratory for the first time. In 1885, after the wave-lengths of the new lines had been carefully measured by Cornu and others, it was found by Balmer that the wave-frequencies are harmonically related, in accordance with a simple formula. In 1868 the visible members of the series had been observed in the spectrum of the solar chromosphere, and in 1891 the ultra-violet members were found by the aid of photography. It was still a mystery, however, why the spectrum of hydrogen should apparently contain only a single series of lines, for the spectra of most of the other elements have been shown by Kayser and Runge to give two or more such series. It is only in the present year that a second series has been found, not yet in the laboratory, but in the spectrum of an inconspicuous southern star, which in all probability would have retained its secret for many years longer, had it not been for Professor Pickering's extensive explorations with the objective prism as a part of the Henry Draper Memorial. Two series thus being known, it might be thought possible to compute the wave-lengths of lines in a third by taking advantage of the important relation discovered by Rydberg, and independently by Schuster and Balmer. This has recently been done by Dr. Rydberg himself, and in the October number of the ASTROPHYSICAL JOURNAL may be found the computed wave-lengths of the lines of the hitherto unknown princi-

pal series. Thanks once more to Professor Pickering's work, the theoretical results find complete confirmation. The faint star *H. P.* 1311 has in its photographed spectrum a bright line at wave-length 4688, while the computed wave-length of the first line in the principal series of hydrogen is 4687.88.[1] There can be little doubt that the line 4687 in the spectra of certain planetary nebulæ, observed many years ago by Sir William Huggins, and more recently by Campbell and others, is the same hydrogen line. Rydberg's computed wave-lengths place the other lines far in the ultra-violet, where atmospheric absorption renders them beyond the reach of observation. It now remains for the physicist to reproduce in the laboratory the special conditions which obtain in the atmospheres of these stars, in order that the two new series may be developed by artificial means.

Illustrations similar to this might easily be multiplied, particularly in the very interesting case of helium. But it is surely unnecessary to dwell longer upon the importance of astrophysical work, or to insist further upon the desirability of bringing about its harmonious development on both the astronomical and physical sides. I must not fail to add, however, that the best results, and the most rapid development of both phases of the subject, are likely to follow when the two are worked out together. Let us suppose that the astrophysicist, while investigating the spectrum of a Sun-spot, or a nebula, or a star, finds some remarkable peculiarity not to be accounted for by appealing to the established results of physics. He may be content to call the attention of physicists to the phenomenon, in the hope that some of them may be ready to drop their own investigations in order to assist in answering the question. But he would certainly regard it as more satisfactory to have at hand a well-equipped laboratory, in which just such experiments as he might wish to make could be performed at any time. To take a definite example, he might find in the spectrum of a Sun-spot a line which for various reasons could be identified as due to a certain element, but which was displaced from its normal position. Now it is known that spectral lines may be displaced in two

ways — (1) by motion in the line of sight; (2) by the effect of pressure. If the displacement is toward the red it may be due to either of these causes. In this connection it becomes important to ascertain just how much pressure is needed to shift the line the measured amount. And it might be hardly less interesting to examine the appearance of the line in order to see how its condition is altered by the pressure to which it is subjected. As for the displacement due to the pressure, we might be fortunate enough to find it in Dr. Humphreys' valuable tables, published in the October ASTROPHYSICAL JOURNAL; but as of necessity no very great number of lines in any one spectrum have been examined by Dr. Humphreys, the chances would be against our finding the desired shift. It may be a long time before more extensive investigations on pressure shifts are made, and one would not like to be compelled to wait for an indefinite period in order to get at a possible interpretation of his results. It is obvious that if the observer had at his command a large spectroscope and a pressure arc mounted ready for immediate use, it would be a comparatively simple matter to experimentally determine the amount of shift for any line at any attainable pressure. The observer would then have under his eyes a phenomenon which he could compare directly with what he had seen or photographed in the Sun-spot. There would be not only the advantage of a saving of time, but in addition to this, and perhaps even more important, would be the advantage which must result from an intimate acquaintance with both the solar and terrestrial phenomena derived from observations made by a single observer.

It seems unnecessary to dwell further upon this point. In it I think we have complete justification for equipping a large observatory in which astrophysical observations are to be made, with complete physical laboratories. This is not a new thing, as you all know. We have a most brilliant example in the case of the Astrophysical Observatory at Potsdam of what may be done in this direction. But in the United States, less for lack of means than for lack of inclination, such observatories have

hitherto been few. In discussing such a matter as this we must not forget the remarkable pioneer work of Rutherfurd and Draper, whose observatories were at the same time laboratories, and whose investigations were almost as important to physics as to astronomy. Nor must we forget the Allegheny Observatory, where Professors Langley, Keeler, and Very have obtained such valuable results in both celestial and terrestrial spectroscopy, nor the Smithsonian Observatory, where the traditions of the Allegheny Observatory are being continued. It has seemed to me, however, from the time when the Yerkes Observatory first acquired a prospective existence, that there was good reason to give further expression to this idea. Accordingly this Observatory has been planned in such a way as to give opportunity for various physical investigations, interesting and valuable in themselves, and also in their connection with astrophysical work.

While the plans were being made I was fortunate enough to have frequent access to the Potsdam Observatory, and from an acquaintance with its arrangement acquired at that time, as well as from kindly suggestions from Director Vogel and other members of the staff, many ideas which have been embodied in this Observatory were obtained. Valuable suggestions received from other astronomers and physicists have also been adopted. I will not burden you with a detailed description of the building. It is before your eyes and ready for your inspection. The equipment, it is true, is still far from complete, and much remains to be done to put the Observatory in working order in all its departments.

But I must point out that these departments are intended to include not only astrophysical work, but other classes of astronomical investigation as well. In completing the equipment it will be our aim to secure an observatory in which any phase of an astronomical, astrophysical or related physical problem can be investigated. It is very far from our desire, in giving such expression as will be given here to astrophysical work, to in any way crowd out the long established traditions of the astronomy of position. On the contrary, it is

fully recognized that questions of position and of motion are equally important with questions of constitution and physical condition. If we are at work upon a star we must not be content to investigate its spectrum, to determine the chemical composition of its atmosphere, the conditions of temperature and pressure that exist in it, and the motion of the star in the line of sight. Surely there is no fundamental peculiarity that makes the component of the motion which lies in the sight-line more interesting than the component at right angles to it. Thus there may well be associated with the astrophysical investigations just referred to researches on the absolute position of the star and upon its proper motion. Parallax investigations may advantageously be carried on simultaneously, and in fact we can omit from consideration none of the methods or problems of the astronomy of position. It is hoped, then, that when instruments and staff are sufficiently large to permit investigations to be undertaken in these various fields of research, that astronomical, astrophysical and physical problems may receive the attention they deserve.

But so ambitious a programme is not to be developed in the first few years of the Observatory's history. While our staff is small and our instruments comparatively few, we must confine our attention to those fields where our equipment and the special tastes of our observers give promise of the best results. To determine, then, the best fields of investigation to be pursued at the present time, it seems to me that we should consider the special qualities of the large telescope. In subjecting this instrument to a series of tests we have found that these qualities are just what we might have expected them to be. You may perhaps be interested to know what these tests have been, and how they have resulted. On account of its great size and excellence, and the important work which has been done with it, the Lick telescope has naturally served as our standard in all comparisons.

The resolving power of the object-glass has been tested by Professors Burnham and Barnard by observing very close

double stars. Such an object as Kappa Pegasi, the components of which are now less than a tenth of a second apart, was clearly and beautifully seen as an elongated disk under a power of 2080. As the theoretical resolving power is about one-tenth of a second, this observation could not have been more satisfactory. Close double stars were subsequently seen by Professor Barnard with a power of 3750 so well defined that micrometrical measurements could easily have been made. As it is probable that so high a power as this has not previously been advantageously used with any telescope, it would seem that no better proof could be offered of the excellence of the object-glass. I should also mention that Professor Barnard has picked up four or five very close new double stars. Incidentally it may be added that the atmospheric conditions which would permit the use of a power of 3750 must have been of the very best. Of course such powers cannot be used often; but Professor Barnard has found that the best nights here are fully as good as the best nights at the Lick Observatory, though the average night seeing is not as good as it is at Mt. Hamilton. Of the day seeing I shall speak further on.

As for the light-gathering power of the telescope, this seems to be quite as great as the large aperture would lead one to expect. Perhaps the best proof of this is afforded by Professor Barnard's observation of a new companion to Vega, which had not been seen with the Lick telescope. The distance of this object from Vega is too great to permit us to suppose that there is any physical connection between the two bodies, and the discovery is therefore to be regarded as of no special astronomical significance. But it does afford excellent evidence of the light-gathering power of the object-glass, as well as the perfection of polish, for without this latter quality so faint an object would not be visible in the immediate neighborhood of so bright a star.

Nebulæ, too, are beautifully seen with the Yerkes telescope. Professor Barnard has examined many of these objects with which he had become familiar at Mt. Hamilton, and he assures

me that he now sees them better than he could see them with the Lick telescope. Without making any special search for them he has already discovered some twenty new nebulæ. Hind's remarkable variable nebula in Taurus has recently been seen here by Professor Barnard, although it was invisible when last looked for at Mt. Hamilton. It may be that the present visibility is due to an increased brightness, but Professor Barnard is inclined to attribute it to the instrument with which the observations were made.

I have obtained further proof of the great light-gathering power of the object-glass in some preliminary work on stellar spectra. The star images are extremely bright and the exposure times in making photographs are correspondingly short.

Another peculiarity of the Yerkes telescope, which Professor Barnard finds to be of the highest importance in his micrometrical work, is the remarkable steadiness of the mounting. A reference to some of Professor Barnard's measures will illustrate this better than any mere description could do. The difference of declination between Atlas and Pleione was recently measured on five successive nights (the telescope being in motion) with the following results: Aug. 27, 300″.65; Aug. 29, 300″.60; Sept. 2, 300″.66; Sept. 3, 300″.72; Sept, 4, 300″.67. It will be noticed that the distance is a large one to measure with an ordinary filar micrometer, and yet the greatest difference between any two observations made on different nights amounts to only 0″.12. It will be interesting to compare this with some of Professor Barnard's previous measures which he had always considered very satisfactory. In 1893 he measured the distance between Nova Aurigae and a neighboring star with the Lick telescope. Measures made on thirty-two nights gave a distance of about seventy-four seconds, the greatest difference between any two observations made on different nights amounting to 0″.60. Five successive observations are given for comparison with the more recent measures: 74″.73, 74″.53, 74″.38, 74″.33, 74″.69. The difference in the character of the objects, which may affect the results to some extent, should, however be taken into

consideration. Professor Barnard has made with the Yerkes telescope a number of micrometrical observations of the satellite of Neptune, the planetary nebula *N. G. C.* 7662, and other objects, and in every case has found his measures to be of great precision.

The great object-glass has received another and a different test in my own observations of the Sun. Fortunately for this work the atmospheric conditions enjoyed here in the day time are exceptionally good. For instance, I have seen the details in the solar chromosphere and prominences beautifully defined under a power as high as 600, which would usually be regarded as excessive for such work. But the special advantages of this satisfactory combination of good atmospheric and instrumental conditions have been most clearly emphasized in observations of the spectrum of the Sun's limb. It has been found that the quiet chromosphere gives many bright lines not hitherto recorded, even in the case of violent eruptions. Among these we may probably include the green fluting of carbon. So many new lines have already been seen that it seems desirable to undertake a complete revision of the chromospheric spectrum.

The success of these various tests convinces me of the desirability of carrying into effect the plan of work mapped out for this Observatory in 1892. This includes various classes of solar investigation; micrometrical observations of double stars, planets, satellites, nebulæ, comets, etc; parallax work; photographic studies of stellar spectra, including determinations of motion in the line of sight; and various physical researches in the laboratories. Miss Bruce's recent gift of a ten-inch photographic telescope will render possible additional photographic observations of many celestial phenomena. Later, when increased staff and instrumental equipment permit, it may become possible to enter other fields. But for the present we may profitably confine our attention to the investigations just enumerated.

I venture to invite your special attention to the instrument and optical shops of the Observatory, for I believe them to be a most important adjunct in our work. With the facilities here

provided it is possible to construct the various pieces of special apparatus which are constantly in demand, particularly in astrophysical and physical work. At the present time you will see in process of construction a 24-inch heliostat, an equatorial mounting for a 24-inch reflecting telescope, a ruling machine for optical gratings, a solar spectroscope and spectroheliograph for the 40-inch telescope, and a 60-inch mirror for stellar spectroscopic work. In this connection I cannot omit to express my appreciation of the services rendered by Professor Wadsworth in designing instruments, and supervising their construction. Mr. Ritchey has done valuable work, not only in making optical surfaces, but also in designing the large grinding machine, a considerable part of which he has built with his own hands. Much credit for the excellent work of the instrument shop is due to Messrs. Lorenz, Mors, and Kathan, who have proved themselves most efficient. In fact, not only in the shops, to which I have alluded on account of the special place they occupy in this Observatory, but in all the phases of our work of preparation, each member of the staff has fully done his part.

I wish to acknowledge at this time the obligation of the Yerkes Observatory to the many institutions and individuals whose gifts of books have enriched our library. For these liberal donations we return our warmest thanks. Nor must we forget those who have contributed so much to the success of these conferences by loaning instruments for the demonstrations. From its very inception the Observatory has received the support of men of science in all parts of the world. For all these evidences of interest in our work we are deeply grateful.

The time has now come when we may turn from anticipation to realization, from planning to performance. We have before us the serious task of carrying into execution the investigations which have been projected. It is the ambition of the members of the Observatory staff that the work to be done here shall acquire a reputation for thorough reliability. We mean to do all we can to discourage sensationalism, the evils of which

have been only too apparent in recent astronomical literature. Finally, we share the hope expressed by Mr. Yerkes that this Observatory may take its place among sister institutions, not as a rival, but as one which would gladly do its part in the advancement of a common cause.

SPECTROSCOPIC NOTES.[1]

By Sir William and Lady Huggins.

ON THE SPECTRA OF THE STARS IN THE TRAPEZIUM OF THE GREAT NEBULA OF ORION.

In our original photographs of the spectrum of the Great Nebula of Orion, including that of the Trapezium stars,[2] we observed and measured in the continuous spectra of these stars a number of bright lines which appeared to extend into the nebula on both sides, and which consequently justified us in concluding that these stars are, or had been, physically connected with the nebula itself.

These bright lines, however, have not been recorded as present in the photographs which have been taken subsequently by other observers. For this reason we thought it desirable to attempt to reproduce the small original negatives by a method of direct enlargment. These enlargements show the bright lines, of which measures were given, together with the blotchy character of the chief nebular lines, and the other points to which attention was directed in our papers.

In consequence, however, of the long exposure which was given to the plates in order to bring out the fainter nebular lines, the continuous spectra of the Trapezium stars were so much over-exposed as to cause the dark lines to disappear, and so these were not observed by us in these early photographs.

Copies of the enlargements accompany these notes. If they cannot be succesfully reproduced as illustrations, I should be glad for them to be placed in the Yerkes Observatory for reference.[3]

During the last three years, by means of the newer form of my reflection-slit, we have succeeded in obtaining separate pho-

[1] Read at the conferences held in connection with the dedication of the Yerkes Observatory, Oct. 18, 1897.

[2] *Proc. R. S.*, 46, 40; 48, 213.

[3] It unfortunately seems to be impossible to successfully reproduce these photographs by the means at our disposal.—Eds.

tographs of the three brightest stars of the Trapezium. The true character of these spectra was observed by us in a photograph taken in 1894, but we have put off publishing an account of them in the hope of being able to obtain more complete results. The unusual bad weather during the last two winters, and some other unavoidable circumstances, have made it impossible for us to take photographs as rich in detail as it would be easily possible to get under more favorable circumstances. We think that it would be desirable now, without any further delay, to publish a short preliminary note about them.

The photograph of 1894, together with photographs taken subsequently in 1895, 1896, and 1897, show that we have to do with a spectrum, which by the peculiar association of bright lines and dark lines suggests the class to which β Lyrae belongs, and possibly to some extent that of Nova Aurigae soon after its first appearance, though it differs from the spectra of both these stars in many points.

In the spectrum of the principal star of the Trapezium the hydrogen series can be traced as far as $H\pi$. The calcium line K is very thin, and appears to be near, or upon, a bright radiation, which may or may not be associated with it. The spectrum is rich throughout in absorption lines and in bright radiations, with the special character strongly marked of bright bands associated with corresponding dark absorption lines. The dark lines are not usually symmetrically placed upon the bright bands, but in most cases the bright band is chiefly, or altogether, on one side of the corresponding dark line.

A comparison of the photographs of the same star taken from 1894 to 1897 leaves no doubt in our minds that the relative positions of the dark and of the reversed bands appear to be subject to change. For example, in the 1894 photograph, the bright hydrogen radiation was mainly on the blue side of the dark band, while in 1897 it seems to be chiefly on the other side of the absorption line.

Bright lines are present in the spectrum of this star about the place in the spectrum where the bright lines were measured

by us in our early photographs. If the weather favors us, we confidently hope to take photographs which will permit of the measurements of these lines under considerable magnification.

The spectra of the second and of the third star are similar in character to that of the first.

It does not come within the scope of this purely preliminary note, and indeed it would be premature, to attempt any discussion of the possible physical conditions prevailing in these stars, and of their probable evolutional connection with the nebula itself.

Enlargements from the original negatives of the spectra of these stars are sent herewith.

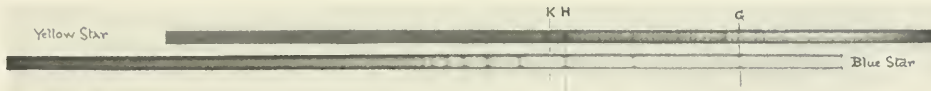
ON THE SPECTRA OF THE COLORED COMPONENTS OF β CYGNI.

This star is a fine example of a class of double stars of which the components are strongly contrasted in color. It is not necessary to say that the colors are real, though, no doubt, the impression of difference of color which the eye receives is heightened by the effect of contrast, through the nearness of the stars.

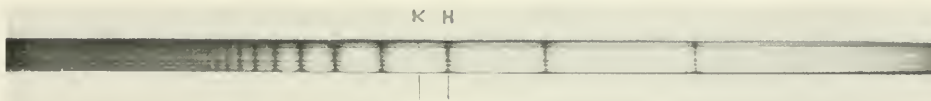
In 1864, I pointed out, as an obvious corollary from the observations of the spectra of stars by myself and Dr. Miller, that the origin of the contrasted colors in pairs of stars is to be sought for in the nature and the condition of the substances by which the light is radiated and absorbed. This view was confirmed by us by the direct observation by eye of the spectra of the components of α Herculis and of β Cygni.

The study of the physical conditions, as revealed by their spectra, of the colored components in pairs of stars has now become of great interest through Dr. See's theory of the tidal evolution of binary stars. On this theory we must assume both stars to be of the same age, and to be composed of the same substances, though not necessarily in the same proportions. The spectra of such pairs of stars should then indicate the relative evolutional stages which the components had severally reached; the life-history of a star being passed through more rapidly, and so the several stages coming in at an earlier date,

PLATE XIX.



SPECTRA OF THE COMPONENTS OF β CYGNI.



SPECTRUM OF α LYRAE.

it may be presumed, in the case of the component which has the smaller mass.

A similar reasoning would lead to the conclusion that the pairs which have reached a more advanced type of spectrum came into being, as double stars, at an earlier date than those of which the spectra of both components are still in an early stage.

We are able to point out a remarkable example of a relatively late separation of the original mass in the case of Cor Caroli. Our photographs show that the brighter component is still in the white-star stage, with the calcium line K very thin; while the less bright star belongs also to the same type, but with a marked increase in the thickness of K, which, however, still remains thinner than H.

On the other hand, the advanced condition, shown by the spectra of both components of γ Leonis, would put back the coming into existence of this pair by evolutional separation, to a much earlier time; unless, indeed, the total mass of matter in both stars is much smaller than it is in Cor Caroli.

In α Herculis the spectrum of the brighter star has reached the Class III *a*.

To return to the relative evolutional progress of the components of one system; here we should expect the brighter star to show an earlier type of spectrum. Now, such is not the case in the spectra of the strongly contrasted colored components of β Cygni, of which enlargements are herewith presented (Plate XIX).

It is the spectrum of the feebler star, of the 5.3 mag. only, which is still of the white-star type, while the brighter star of the 3 mag. gives a spectrum which shows that it is well on the way towards the solar stage, though the calcium line K is still less broad than the calcium-hydrogen line H. The visual colors of the two components correspond to these stages. The small star having the bluish-white color characterizing the stars which we regard as in an early stage, while the brighter star is yellow, resulting from greater enfeeblement of the blue by incoming absorption.

It is true that in this pair no relative motion has been detected, and that the distance apart of the stars is over the arbitrary limit assigned by Struve to true double stars, but it seems to me more than probable that we ought to regard them as evolutionally connected.

We have, therefore, to face the apparent anomaly that it is the "larger" star which is in the more advanced stage of development. It may reasonably be suggested that we really know nothing of the true relative masses of the stars, and that we have no certain ground for assuming that the brighter star is actually the larger one.

I have pointed out elsewhere[1] that the brightness of a star, that is the luminous energy radiated from it, depends upon several conditions, and must be largely affected by the nature and the conditions of the substances by which the light is chiefly emitted, as well as by the amount and the conditions of the absorbent atmosphere through which it has to pass. It is conceivable, therefore, that the blue star, though less brilliant, is of greater size, and so remains still in an earlier evolutional stage.

Another way of looking at the problem is perhaps possible. May it be that the effect of great mass on surface density, together with the working of Lane's law, by which the temperature of a condensing gaseous mass, so long as it is subject to the laws of a purely gaseous body, will continue to rise, will favor in such stars the coming in of a solar type of spectrum at a somewhat relative earlier time?

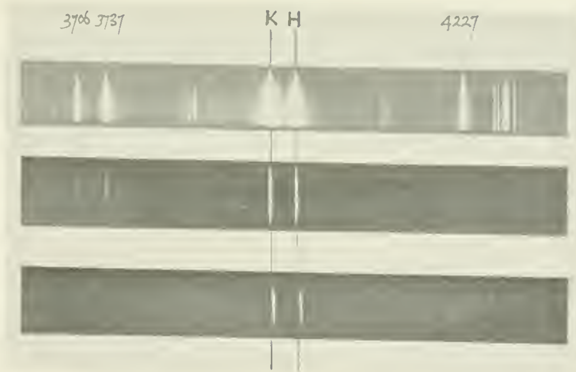
ON THE ULTRA-VIOLET SPECTRA OF α LYRAE, AND OF ARCTURUS.

I take this opportunity of sending a photograph of the spectrum of α Lyrae, which shows with great completeness the lines of the hydrogen series. In the negative sixteen lines can be counted beyond $H\epsilon$, so bringing the series up to $H\phi$.

As the exposure was timed for the ultra-violet part of the hydrogen series, the blue part of the spectrum has been over-

[1] Address Brit. Assoc. 1891, pp. 15, 16.

PLATE XX.



SPECTRUM OF CALCIUM.

exposed for the crowd of fine dark lines between the hydrogen bands, which, in consequence, are only faintly visible. On the other hand the extreme ultra-violet has been greatly under-exposed, though it may still be faintly traced as far as λ 3250. A longer exposure would be needed to bring out this part of the spectrum strongly, and as far as λ 2970, to which we were able to trace the star's spectrum in a photograph taken in 1888.[1]

This photographic difficulty has been got over in the case of the spectrum of Arcturus by placing together parts of three photographs taken with different lengths of exposure, so as to give to each part of the spectrum an exposure suitable for it. On account of the great range of wave-length covered by these spectra a very moderate degree of enlargement only, has been employed.

EFFECT OF DENSITY ON THE SPECTRUM OF CALCIUM.

The three photographs (Plate XX) show in a very striking way the effect of great tenuousness of calcium vapor in reducing the spectrum to the two lines H and K, and the greater strength of K relatively to H, as the tenuity is increased.

No. 1 shows the spectrum with a feeble spark between electrodes of metallic calcium.

No. 2. Spectrum of a similar spark between platinum electrodes, moistened with a weak solution of fluoride of calcium, and then well washed. The line at 4227 has all but disappeared, but the more refrangible pair faintly present, 3706 being stronger than 3737.

No. 3. Similar spark between platinum eloctrodes touched with moistened magnesia which contained a trace, as an impurity, of lime. H and K strong and alone. A faint trace of the magnesium triplet on the more refrangible side of K. The line K distinctly stronger than H. Both lines thin and defined.

TULSE HILL OBSERVATORY,
London, Sept. 29, 1897.

[1] *Proc. R. Soc.*, **46**, 133.

NEW INVESTIGATIONS OF THE SPECTRUM OF β LYRAE.

By A. BÉLOPOLSKY.

My investigations of this star in 1892 (*Bull de l'Acad. de S. Pétersbourg*), based on spectrograms of the region D–$H\gamma$, have shown that almost all the spectral lines vary with the light of the star, but that the true form of the dark and bright lines can hardly ever be determined, because they are always superposed.

The dark line of magnesium $\lambda = 4482$ seems to be the only one which preserves its form; its wave-length was determined, but on account of the fact that this line is found at the extremity of the spectrum, and also because of insufficient dispersion and a lack of suitable artificial lines, no decisive conclusions could be based upon these determinations. It was necessary to wait until I had at my disposal more powerful optical apparatus than that used in the earlier work. It is only at the present time (summer of 1897) that this desire has been realized.

Our large refractor now possesses a correcting lens for the actinic rays, and our large spectrograph with two Halle prisms has been supplied with a large collimator. Thanks to these two arrangements I have been able to secure spectra of stars to the 4.5 magnitude without prolonging the time of exposure beyond an hour; and I have undertaken to make a new collection of spectrograms of β Lyrae with iron lines for comparison. Between June 20 and August 2, when it was necessary to interrupt my observations on account of important repairs undertaken in the large dome, I obtained twenty-six spectrograms corresponding to all the phases of brightness.

Measures of the line 4482 were made according to a method described in my article on the spectrum of η Aquilae (see *Mem. Spettr. Ital.*) by means of the artificial lines 4384, 4405, 4415, and 4529, and a solar spectrogram which was superposed during

the measures on the spectrogram of the star. A microscope magnifying fifteen diameters was employed.

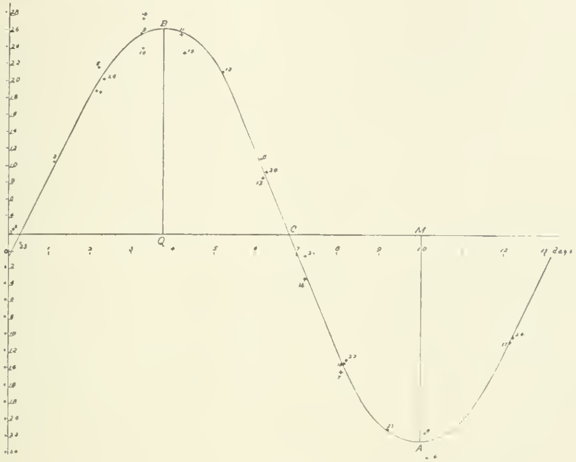


FIG. 1.

In order to give an idea of the character of the line 4482 and its surroundings I add a description of this part of the spectrum. None of the other lines can be utilized, and for this reason I have omitted them from the list. The descriptions are based upon an arrangement of the spectrograms according to epochs counted from the principal minimum (see the curve in Fig. 1).

1897

June 22, No. 2, $\lambda = 447$, dark, sharp; a very distinct bright line on the red side; $\lambda = 448$, broad, diffuse, dark; a bright line on the violet side; on account of the contrast there seems to be another dark line between the lines 447 and 448.

July 31, No. 25, $\lambda = 447$, dark, distinct, with a bright line on the red side; $\lambda = 448$, dark, sharp, single.

June 23, No. 3, $\lambda = 447$, dark, very strong, a very brilliant bright line on the red side ; $\lambda = 448$, dark, broad, very diffuse.

June 24, Nos. 4 and 5, $\lambda = 447$, dark, sharp ; a bright line on the violet side ; $\lambda = 448$, dark, sharp ; narrower than in the preceding plate.

August 2, No. 26, $\lambda = 447$, dark, sharp, with a maximum ; bright line lacking ; $\lambda = 448$, dark, sharp, very narrow.

July 8, Nos. 9 and 10, $\lambda = 447$, dark, sharp, very narrow ; $\lambda = 448$, dark, broader than in the preceding plate. The background of continuous spectrum between 447 and 448 seems to be bright.

July 21, No. 18, $\lambda = 447$, dark, narrow ; $\lambda = 448$, dark, sharp, very narrow ; traces of a bright line on the violet side.

July 9, No. 11, $\lambda = 447$, dark, very faint ; it is suspected that the spectrum contains many faint dark lines ; $\lambda = 448$, dark, sharp ; a bright line on the violet side.

July 10, No. 12, $\lambda = 447$, neither dark nor bright ; $\lambda = 448$, dark, very sharp ; perhaps a faint bright line on the violet side.

July 22, No. 19, $\lambda = 447$, dark, very faint ; bright line lacking ; $\lambda = 448$, dark, sharp ; a faint bright line on the violet side.

June 28, No . 6, $\lambda = 447$, dark, sharp ; a bright line on the violet side. $\lambda = 448$, dark, sharp ; a broad, bright line fills the entire space between 447 and 448.

July 24, No. 20, $\lambda = 447$, dark, sharp ; two bright lines on the violet side ; the one near the dark line is brighter than the other ; $\lambda = 448$, dark, distinct ; bright line altogether lacking.

July 11, No. 13, $\lambda = 447$, a hazy, dark line ; on the violet side a distinct bright line ; there is also one on the red side, but it is less distinct ; $\lambda = 448$, dark, sharp ; bright line lacking.

July 12, No. 10, $\lambda = 447$, dark, pretty faint ; traces of a bright line ; $\lambda = 448$, dark, sharp.

July 25, No. 21, $\lambda = 447$, dark, pretty faint ; in the middle of a bright line ; $\lambda = 448$, dark, very sharp ; this spectrogram contains a number of very delicate dark and bright lines, particularly in the part of the spectrum between 448 and F.

June 30, No. 7, $\lambda = 447$, the dark line is lacking, but a broad dark band, with two very faint maxima of intensity, is present ; $\lambda = 448$, dark, sharp.

July 13, No. 15, $\lambda = 447$, two dark lines, very faint, which are perhaps due to the contrast between certain bright lines ; $\lambda = 448$, dark, distinct.

July 26, No. 22, $\lambda = 447$, it is clearly seen that the two dark lines are due to contrast between three bright lines ; the bright line which is in the middle is the brightest and narrowest. Its position is nearer the red side ;

$\lambda = 448$, dark, sharp; a bright line on the red side. This spectrogram contains many bright lines, *e. g.*, in the region $\lambda = 455$, where five are easily seen; further on there are others.

July 27, No. 23, $\lambda = 447$, two dark lines have become visible between the bright lines. The bright line which separates them is very brilliant; $\lambda = 448$ dark, sharp; possibly the edges are bright. On this spectrogram there are many dark lines, particularly in the region $\lambda = 455$.

July 2, No. 8, $\lambda = 447$, two distinct dark lines and two pretty strong bright ones. The dark line which lies between the bright lines is sharper than the other; $\lambda = 448$, dark, sharp. Several very faint lines are visible.

July 15, No. 16, $\lambda = 447$, dark, sharp; the edges are bright. There is also a second dark line on the red side; $\lambda = 448$, dark, pretty faint.

June 20, No. 1, $\lambda = 447$, dark, distinct, narrow; the violet edge is bright; $\lambda = 448$, dark, sharp.

July 17, No. 17, $\lambda = 447$, a complicated appearance; a narrow bright line on the violet edge of a broad dark band. Near the other edge a second narrow bright line appears in this band. The space between this last and the red edge appears like an isolated dark line; $\lambda = 448$, similar to the line 447, but all the parts are closer together, in such a way as to give the appearance of a single sharp, dark line with bright edges; that on the red side is brighter than the other; there is also in the neighborhood a pretty faint, dark line.

July 30, No. 24, $\lambda = 447$, this resembles the preceding spectrogram, but is not so sharp. The second bright line is broader than on the preceding spectrogram, and is situated nearly in the center of the dark band; $\lambda = 448$, dark, sharp.

This description affords sufficient support to the opinion already expressed that the dark line at $\lambda\,4482$ changes but little in appearance, while the lines 447, $H\gamma$ and F (see my 1892 investigations) undergo great changes. However, the measures of the above mentioned line can give no very great precision because of certain peculiarities in its form.

I give below the results of the measures of the line at $\lambda\,4482$ referred to a solar spectrogram. Let d_1 be the difference between the readings on the micrometer head for settings on the artificial lines and the corresponding solar lines; d_2 the difference between the settings on the line at $\lambda\,4482$ in the stellar and solar spectra. The sum $d_1 + d_2$ gives the displacement of the line at $\lambda\,4482$ expressed in parts of the revolution of the screw.

1897.

June 20

λ	d_1
4529	−0.275
4495	−0.256
4476	−0.223
4467	−0.193
4415	−0.176

For

$\lambda = 4482$ $d_1 = -0.233$

$d_2 = +0.744$

Displacement $= +0.511$

June 22

λ	d_1
4529	−0.049
4415	−0.048
4405	−0.028

For

$\lambda = 4482$, $d_1 = -0.044$

$d_2 = -0.049$

Displacem't $= -0.093$

June 23

λ	d_1
4529	+0.149
4467	+0.127
4415	+0.091

For

$\lambda = 4482$, $d_1 = +0.125$

$d_2 = -0.450$

Displacem't $= -0.325$

June 24, 1st sp.

λ	d_1
4529	+0.368
4405	+0.345
4384	+0.363

For

$\lambda = 4482$, $d_1 = +0.364$

$d_2 = -0.931$

Displacem't $= -0.567$

June 28

λ	d_1
4529	+0.237
4405	+0.152
4384	+0.148

For

$\lambda = 4482$, $d_1 = +0.198$

$d_2 = -0.533$

Displacem't $= -0.335$

June 30

λ	d_1
4529	+0.260
4468	+0.202
4415	+0.197
4384	+0.165

For

$\lambda = 4482$, $d_1 = +0.218$

$d_2 = +0.184$

Displacem't $= +0.402$

July 2

λ	d_1
4529	+0.351
4415	+0.304
4384	+0.283

For

$\lambda = 4482$, $d_1 = +0.320$

$d_2 = +0.294$

Displacem't $= +0.614$

July 8, 1st sp.

λ	d_1
4529	−0.303
4415	−0.302
4405	−0.340
4384	−0.337

For

$\lambda = 4482$, $d_1 = -0.308$

$d_2 = -0.451$

Displacem't $= -0.759$

July 8, 2d measure

λ	d_1
4529	−0.258
4405	−0.299
4384	−0.313

For

$\lambda = 4482$, $d_1 = -0.270$

$d_2 = -0.473$

Displacem't $= -0.743$

July 8, 2d sp.

λ	d_1
4529	−0.244
4405	−0.290
4384	−0.307

For

$\lambda = 4482$, $d_1 = -0.257$

$d_2 = -0.444$

Displacem't $= -0.701$

June 24, 2d sp.

λ	d_1
4529	−0.212
4415	−0.224
4384	−0.218

For

$\lambda = 4482$, $d_1 = -0.217$

$d_2 = -0.432$

Displacem't = −0.649

July 9

λ	d_0
4529	+0.373
4405	+0.347
4384	+0.333

For

$\lambda = 4482$, $d_1 = +0.364$

$d_2 = -1.109$

Displacem't = −0.745

July 12

λ	d_1
4529	+0.391
4405	+0.330
4384	+0.299

For

$\lambda = 4482$, $d_1 = +0.364$

$d_2 = -0.266$

Displacem't = +0.098

July 17

λ	d_1
4529	+0.312
4415	+0.292
4405	+0.291
4384	+0.296

For

$\lambda = 4482$, $d_1 = +0.304$

$d_2 = -0.019$

Displacem't = +0.285

July 10

λ	d_1
4529	+0.375
4476	0.391
4405	0.334
4384	0.327

For

$\lambda = 4482$, $d_1 = +0.366$

$d_2 = -0.982$

Displacem't = −0.616

July 13

λ	d_1
4529	+0.801
4405	0.739
4384	0.731

For

$\lambda = 4482$, $d_1 = +0.777$

$d_2 = -0.390$

Displacem't = +0.387

July 17, 2d measure

λ	d_1
4529	−0.157
4415	0.136
4405	0.140

For

$\lambda = 4482$, $d_1 = -0.149$

$d_2 = +0.483$

Displacem't = +0.334

July 11

λ	d_1
4529	−0.221
4405	0.271
4384	0.285

For

$\lambda = 4482$, $d_1 = -0.243$

$d_2 = -0.011$

Displacem't = −0.254

July 15

λ	d_1
4529	+0.049
4415	0.002
4405	0.005
4384	0.002

For

$\lambda = 4482$, $d_1 = +0.021$

$d_2 = +0.688$

Displacem't = +0.709

July 21

λ	d_1
4529	−0.091
4415	0.046
4405	0.059
4384	0.078

For

$\lambda = 4482$, $d_1 = -0.061$

$d_2 = -0.726$

Displacem't = − 0.787

July 22

λ	d_1
4529	−0.226
4415	0.267
4405	0.261
4384	0.260

For

$\lambda = 4482$, $d_1 = -0.243$

$d_2 = -0.425$

Displacem't = −0.668

July 26

λ	d_1
4529	+0.255
4495	0.199
4476	0.227
4467	0.228
4405	0.220

For

$\lambda = 4482$, $d_1 = +0.228$

$d_2 = +0.162$

Displacem't = +0.390

July 31	
λ	d_1
4529	−0.052
4415	0.076
4405	0.080
4384	0.091

For
$\lambda = 4482,\ d_1 = -0.062$
$d_2 = +0.056$

Displacem't = −0.006

July 24	
λ	d_1
4529	−0.050
4415	0.081
4405	0.078
4384	0.079

For
$\lambda = 4482,\ d_1 = -0.064$
$d_2 = -0.189$

Displacem't = −0.253

July 27	
λ	d_1
4529	+0.007
4476	+0.003
4467	+0.021
4405	−0.019
4384	−0.021

For
$\lambda = 4482,\ d_1 = +0.006$
$d_2 = +0.625$

Displacem't = +0.631

August 2	
λ	d_1
4529	+0.185
4495	0.145
4476	0.162
4415	0.151
4405	0.144
4384	0.129

For
$\lambda = 4482,\ d_1 = +0.171$
$d_2 = -0.737$

Displacem't = −0.566

July 25	
λ	d_1
4529	−0.109
4415	0.147
4405	0.160
4384	0.164

For
$\lambda = 4482,\ d_1 = -0.126$
$d_2 = +0.159$

Displacem't = +0.033

July 30	
λ	d_1
4529	+0.004
4415	−0.004
4405	+0.015
4384	−0.002

For
$\lambda = 4482,\ d_1 = +0.003$
$d_2 = +0.314$

Displacem't = +0.317

To find the radial velocities in geographical miles I have calculated the coefficient K from the measures made on several solar spectrograms. As argument, instead of the temperature, I have always employed the length of the interval λ 4405 − 4308 expressed in revolutions of the screw. In this way the following table has been obtained:

Argument	K	log. K	Argument	K	log. K
30.02	34.45	1.5372	30.09	34.40	1.5366
.03	.44	.5371	.10	.39	.5364
.04	.43	.5370	.11	.39	.5364
.05	.43	.5370	.12	.38	.5363
.06	.42	.5369	.13	.37	.5362
.07	.41	.5367	.14	.36	.5361
.08	.41	.5367	.15	.36	.5361

The following table contains the results of the measures and computations. The last column contains the intervals of time between the principal minimum and the moment of observation.

No.	Pulkowa mean time	Displacement	Radial velocity (geog. miles)	Radial velocity (kilom.)	Reduction to Sun (geog. miles)	Reduction to Sun (kilom.)	Velocity relative to Sun (geog. miles)	Velocity relative to Sun (kilom.)	Interval from minimum
1..	1897, June 20 11h.5	+0.511	+17.60	+130.6	+0.67	+5.0	+18.27	+135.6	11d 1h
2..	22 12 .0	−0.093	−3.20	−23.8	+0.60	+4.5	−2.60	−19.3	0 3
3..	23 12 .4	−0.325	−11.19	−83.0	+0.57	+4.2	−10.62	−78.8	1 3
4..	24 11 .8	−0.567	−19.54	−145.0	+0.53	+3.9	−19.01	−141.1	2 3
5..	24 12 .5	−0.649	−22.33	−165.7	+0.53	+3.9	−21.80	−161.8	2 4
6..	28 11 .6	−0.335	−11.53	−85.6	+0.39	+2.9	−11.14	−82.7	6 3
7..	30 11 .1	+0.402	+13.85	+102.8	+0.31	+2.3	+14.16	+105.1	8 2
8..	July 2 11 .9	+0.614	+21.14	+156.9	+0.24	+1.8	+21.38	+158.7	10 3
9..	8 11 .9	−0.751	−25.86	−191.9	+0.02	+0.1	−25.84	−191.8	3 5
10..	8 12 .5	−0.701	−24.11	−178.9	+0.02	+0.1	−24.09	178.8	3 6
11..	9 11 .4	−0.745	−25.66	−190.4	−0.02	−0.1	25.68	−190.5	4 4
12..	10 11 .1	−0.616	−21.21	−157.4	−0.06	−0.4	−21.27	−157.8	5 4
13..	11 11 .0	0.254	−8.74	64.9	0.09	0.7	−8.83	−65.6	6 4
14..	12 11 .5	+0.098	+3.37	+25.0	−0.13	−1.0	+3.24	+24.0	7 5
15..	13 11 .4	+0.387	+13.32	+98.9	−0.17	−1.3	+13.15	+97.6	8 4
16..	15 11 .4	+0.709	+24.40	+181.1	−0.25	−1.9	+24.15	+179.2	10 4
17..	17 11 .2	+0.310	+10.66	+79.1	−0.32	−2.4	+10.34	+76.7	12 4
18..	21 11 .2	−0.787	−27.05	−200.7	−0.47	−3.5	−27.52	−204.2	3 6
19..	22 11 .2	−0.668	−22.97	−170.4	−0.51	−3.8	−23.48	−174.2	4 6
20..	24 10 .3	−0.253	−8.70	−64.6	−0.58	−4.3	−9.28	68.9	6 5
21..	25 10 .2	+0.033	+1.14	+8.5	−0.61	−4.5	+0.53	+4.0	7 5
22..	26 10 .0	+0.390	+13.42	+99.6	−0.65	−4.8	+12.77	+94.8	8 5
23..	27 10 .2	+0.631	+21.71	+161.1	−0.68	−5.0	+21.03	+156.1	9 5
24..	30 10 .1	+0.317	+10.90	+80.9	−0.79	−5.9	+10.11	+75.0	12 5
25..	31 10 .2	−0.006	−0.21	−1.6	−0.82	−6.1	1.03	−7.7	0 7
26..	August 2 9 .7	−0.566	−19.47	−144.5	−0.89	−6.6	−20.36	−151.1	2 7

The argument measured on each spectrogram of the star is:

June 20	30.04	July 9	30.02	July 22	30.11
22	.11	10	.05	24	.11
23	.05	11	.07	25	.05
24	.07	12	.07	26	.08
28	.04	13	.07	27	.09
30	.03	15	.07	30	.11
July 2	.06	17	.10	31	.10
8	.05	21	.10	August 2	.09

Taking 12.908 days as the period of light change, let us draw a curve of radial velocities, using the values given in the preceding table (Fig. 1). According to the *Annuaire du Bureau des Longitudes* the principal minimum occurred:

1897, June 9, 17^h Pulkowa Mean Time; June 22, 7^h; July 5, 7^h; July 18, 5^h; July 31, 3^h.

II Minimum: June 28, 19^h; July 11, 17^h; July 24, 15^h.

I Maximum: June 25, 14^h; July 8, 12^h; July 21, 10^h; Aug. 3, 8^h.

II Maximum July 2, 0^h; July 14, 22^h; July 27, 20^h.

The differences between the curve of the observed velocities can be explained in part by the remarks appended to the measures: July 9, "The line is diffuse and badly defined;" July 15, "Faint;" July 8, "The artificial line at λ 4529 is hardly visible."

By means of the curve which satisfies the necessary conditions, we find the following elements:

Proper motion of the system $= -$ 2.00 geog. miles $= -14.8^{km}$

$Z_1 = +450 \qquad Z_2 + Z_1 = -68$

$Z_2 = -518 \qquad Z_2 - Z_1 = -968$

A $=$ 24.60 geog. miles $= 182.5^{km}$. A + B $=$ 48.8 geog. miles $= 362.1^{km}$

$2\sqrt{A \times B} = 48.80$

B $=$ 24.20 geog. miles $= 179.6^{km}$. A $-$ B $= +0.4$ geog. miles $= 3.0^{km}$

log. tan. $u_1 = 2.0863n$

$u_1 = 90^\circ.4 =$ point at which radial velocity $= 0$

$\log e \cos \omega = 8.8466$

$\log e \sin \omega = 7.9109$

$\tan \omega = 0.9357$

$\omega = 83^\circ.4 =$ long. of periastron.

$e = 0.07 \qquad \left(\frac{dz}{dt}\right) = +3.01$ geog. miles $= 22.3^{km}$

The time of periastron passage $T = +0^d\ 4^h$, or $+7^d\ 1^h =$ the time of apastron passage.

Finally, $a \sin i = 4318000$ geog. miles $= 32^{km} \times 10^6$, and supposing $i = 90^\circ$, $a = 4318000$ geog. miles $= 32^{km} \times 10^6$

The curve of radial velocities shows that the changes of brightness may be sufficiently well explained by an eclipse; for the times of radial velocity $= 0$ are very close to the times of minima I and II.

It may be remembered that I have found that the bright F line also gives periodic radial velocities, and that the semi-axis of the orbit of the star whose spectrum contains this line $=$ 2130000 geographical miles ($15.8 \times 10^{6\,km}$). But although the velocities given by the measures of the dark line at λ 4482 are negative after the principal minimum, those given by the bright F line are positive after the minimum. Thus the dark line at λ 4482 belongs to one star, and the bright F line to another, and during the principal minimum it is the star giving the line at λ 4482 which is eclipsed; during the II minimum the star giving the bright F line is eclipsed.[1]

These results are in accordance with the conclusions of Dr. M. Myers (*Inaugural Dissertation*), and M. Tikhoff (*Mem. Spettr. Ital.*). I hope soon to attempt a further analysis of the bright F line.

[1] In my article "Le spectre de l'étoile variable β Lyrae," page 431, we read: "We thus suppose that the star at the time of minimum brightness is at one of its nodes, or rather that one of the stars of the system is at the node. This hypothesis is based on the fact that the continuous spectrum becomes very faint at the time of the principal minimum, while the bright F line and also the line at λ 5014 do not sensibly diminish in intensity; thus we observe about this time a partial eclipse of one of the stars"—of that which does not give the bright F line.

ON THE CONSTITUTION OF THE RED SPECTRUM OF ARGON.

By J. R. Rydberg.

1. Immediately after the discovery of argon attempts were made by means of spectrum analysis to determine the nature of the new gas. But the curious detection by Crookes[1] of the double spectrum of argon, the red and the blue, instead of clearing up the question, only made it more complicated, by giving rise to the hypothesis that argon was a mixture of two different elements, without affording the means of deciding as to the justness of such a supposition. In order to ascertain whether relations were to be found between the two spectra, I submitted the determinations of Crookes to a careful examination, but with no other result than the conviction that the precision of the measurements did not suffice for the present purpose. A trial with the first wave-length determinations of Eder and Valenta[2] succeeded better, numerous constant differences of wave-numbers being found, and I was about to publish the results obtained, when the first researches of the argon spectra by Kayser,[3] who stated his intention to make similar inquiries, decided me to defer for a time the publication of the relations found. If Professor Kayser were to succeed in arranging the spectra, it would be only just that the satisfaction of drawing the conclusions should follow such a troublesome investigation; if not, the new determinations would be very welcome to strengthen and to complete my former results. In his second publication[4] Kayser has given with a very high degree of precision the wave-lengths of the two spectra of argon. He mentions that he has done a great deal of work in searching for series

[1] *Z. f. phys. Chem.*, **16**, 369–379, 1895.

[2] "Über das rothe Spectrum des Argons." *Akad. Anzeig.*, No. XXI; *Sitz. d. math. naturw. Classe*, **24**, October 1895.

[3] *Chem. News*, **72**, 99, 1895.

[4] This Journal, **4**, 1–17, 1896.

of related lines, but without being successful in this direction. However, as the three pairs of lines given by Kayser as triplets of the red spectrum enter into the grouping of lines which I had already found, it was to be expected that a continuation of the researches would shortly follow. But nothing more has been published, and, in the meantime, a new detailed investigation by Eder and Valenta[1] has further enriched the material for studies of the spectra. Therefore I now deem it proper to publish my observations on the constitution of the red spectrum of argon, deferring for the present the examination of the blue spectrum.

2. According to the statements of Crookes, Kayser, and Eder and Valenta, both spectra of argon can be obtained in Geissler tubes under various conditions, but in general the variations in the intensities of the different spectral lines seem to depend on the quantity of energy which a molecule of the gas receives from the current in unit time, the time, of course, being counted only when a discharge is passing. Every spectral line has a maximum of intensity, corresponding to a certain value of the energy of vibration of the molecule, but varying for different vibrations. The lines which are ascribed to the red spectrum attain their maxima at lower temperatures than those forming the blue spectrum, and disappear gradually when the temperature rises, the lines of the blue spectrum growing stronger. In this way it is possible to obtain at relatively low temperatures a "red spectrum," and at considerably higher temperatures a "blue spectrum," which have no lines in common. In general, however, only "mixed spectra" are produced; but if we adhere to the firm conviction that we really have to do with two different spectra, the difficulty of common lines can be easily overcome by always ascribing the lines which grow weaker at higher temperatures to the red spectrum, and those whose intensity increases under these conditions to the blue spectrum. In this way, I think, both the pure spectra of argon may be obtained.

In order to form a better judgment regarding the agreement

[1] *Denkschr. d. k. Akad. d. W. Wien*, **64**, 1896.

of these views with the details of the various researches we will seek an approximate expression for the energy transmitted by the current to the molecules of the gas. Let V_1 and V_2 be the potentials at the electrodes, which we assume, for greater simplicity, to be directly introduced at the ends of the cylindrical capillary tube; Q the quantity of electricity discharged in the time t (a fraction of the time of the shortest discharge used); l the length and a the sectional area of the tube; n the number of molecules in unit volume at unit pressure and at 0°; and P the pressure of the included gas when at 0°. Then the whole quantity of energy given off by a discharge in unit time is $\frac{Q(V_1 - V_2)}{t}$, and the number of molecules in the tube, $P \cdot n \cdot a \cdot l$. Therefore the quantity of energy transmitted to every molecule in unit time is, in a first approximation,

$$\frac{Q\,(V_1 - V_2)}{t \cdot l \cdot n \cdot P \cdot a}.$$

This expresssion increases with the strength of the current $\frac{Q}{t}$ and with the force $\frac{V_1 - V_2}{l}$; it also increases when the gas is rarefied or when the sectional area of the capillary tube is reduced. According to the experiments of the authors quoted, all these methods of augmenting the energy of the molecules also suffice to transform the red spectrum of argon first into a mixed spectrum and then at last into the pure blue spectrum. Here we have the introduction of a condenser, the strengthening of the current, the change of the pressure, and, finally, the observation of Eder and Valenta that, when the capillary gives the blue spectrum, a mixed spectrum is shown by the light in the wider portions of the tube at both poles. The only observation that cannot be explained in this simple way is the reverse phenomenon, when the red spectrum in the capillary tube corresponds to a mixed spectrum in the wider parts. I think it would be of interest to examine the spectra produced in a tube having a capillary of varying width.

3. I have limited my researches to that part of the red spectrum of argon (4702–2967) which has been determined by Kayser with the greatest precision. Moreover, I have admitted several lines observed by Eder and Valenta which find a place in the discovered grouping of lines, but were not seen by Kayser. It has not been possible to take the less refrangible portion of the red spectrum into account, the greater part of the lines of Eder and Valenta in this region belonging most likely to the blue spectrum, as they give no constant differences, such as those which characterize the red spectrum; while the values of Kayser, which really seem to correspond to the rest of the red spectrum, obviously lack the precision necessary for the present investigation. From the eighty-one lines given by Kayser in this region of the spectrum, at least one-half can be inserted in the same grouping of lines with the others, but as there can be given no sufficient proof of their real correspondence without new and more exact measurements, I have passed over these lines altogether.

The wave-lengths after Kayser (K.) and Eder and Valenta (E. V.), and the computed wave-numbers (number of waves in 1^{cm}) of the lines examined are given in Table I, together with their intensities according to both the series of observations quoted. The last column contains provisional designations for the lines which have been arranged and entered in Table II, and remarks concerning several of the other lines ascribed to the red spectrum of argon.

In examining the last column of the table we see that of the ninety-five lines given by Kayser between 4702 and 2967 not less than fifty-nine are inserted in Table II, among them the two lines 4198.162 and 4191.841, whose considerable deviations from the corresponding values of Eder and Valenta must attract special attention. On closer inspection it appears that these values have been inserted by error instead of 4198.436 and 4191.162, the values given as examples by Kayser on page 8. The line 3564.423 occurs twice, and seems to agree equally well in both places. Possibly the line is double. Of the remaining thirty-six lines

TABLE I.

RED SPECTRUM OF ARGON FROM λ 4702–λ 2967 ACCORDING TO KAYSER AND EDER AND VALENTA.

Obs.	Intensity K.	Intensity E. V.	Wave-length	Wave-number	Designations and remarks
K.	4	5	4702.504	21265.27	A_1
"	3	8	4628.623	21604.70	A_2
"	3	8	4596.205	21757.08	A_3
E. V.	—	5	4589.40	21789.34	A_4 From the red spectrum of E. V. (1)
K.	3	6	4522.389	22112.21	B_1
"	5	10	4510.851	22168.77	A_5
E. V.	—	1	4424.09	22603.52	B_3 From the red spectrum of E. V. (2)
K.	1	4	4363.970	22914.91	C_1
"	4	10	4345.322	23013.25	A_6
"	4	8	4335.491	23065.44	A_7
"	6	6	4333.714	23074.90	A_8
"	1		4304.033	23234.02	Not seen by E. and V. "Ghost" (?)
"	6	10	4300.249	23254.47	C_2
"	6	10	4272.304	23406.57	C_3
"	5	10	4266.425	23438.83	C_4
"	7	10	4259.491	23476.98	A_9
"	3	6	4251.329	23522.06	D_1
"	1	—	4205.007	23781.17	Not seen by E. and V. "Ghost"
"	9	10	4200.799	23805.00	
"	5	10	4198.436	23818.40	C_5 } Corrected values. See K., p. 8 { 4198.162
"	5	10	4191.162	23859.73	B_6 } In the table Kayser has by error { 4191.841
"	5	5	4190.841	23861.56	D_2
"	5	9	4182.002	23911.90	B_7
E. V.	—	2	4180.38	23921.27	B_8 From the white spectrum of E. V. (2)
K.	5	9	4164.309	24013.59	D_3
"	1	—	4162.906	24021.68	Not seen by E. and V. "Ghost"
"	9	10	4158.722	24045.85	D_4
"	2	—	4154.657	24069.38	Not seen by E. and V. "Ghost"
"	2	5	4054.663	24662.96	C_6
"	2	—	4046.620	24711.98	Probably Hg[S_3, 2] = 4046.78 (K. R.)
"	2	6	4046.027	24715.60	C_7
"	7	10	4044.565	24724.54	C_8
E. V.	—	3	4033.11	24794.76	A_{10} From the red spectrum of E. V. (2)
"	—	2	3979.81	25126.83	C_9 From the red spectrum of E. V. (1)
K.	6	10	3949.107	25322.18	D_7
"	4	5	3947.645	25331.56	D_8
"	1	4	3900.065	25640.60	B_{10}
"	2	5	3894.795	25675.29	A_{12}
"	1	2	3866.353	25864.17	A_{14}
"	1	3	3850.693	25969.35	Stronger in the blue spectrum of E. V.
"	4	6	3834.768	26077.20	A_{16}
"	1	—	3801.049	26308.53	Not seen by E. and V.
"	2	4	3781.461	26444.81	C_{10}
"	1	2	3775.476	26486.73	C_{11}
"	3	4	3770.440	26522.10	B_{12}
"	1	1	3743.808	26710.77	B_{14}
"	1	1	3738.030	26752.06	Stronger in the blue spectrum of E. V.
"	1	2	3696.587	27051.98	D_{10}
"	2	4	3691.001	27092.92	D_{11}
"	1	2	3675.353	27208.27	A_{17}
"	2	4	3670.783	27242.14	A_{19}

TABLE I—*Continued.*

Obs.	Intensity K.	Intensity E. V.	Wave-length	Wave-number	Designations and remarks
K.	1	—	3663.392	27297.11	Probably Hg [D_{13}, 2]=3663.25 (K. R.)
"	2	3	3659.632	27325.15	C_{12}
"	1	—	3654.962	27360.07	Probably Hg [D_{12}, 2]=3654.94 (K. R.)
"	2	—	3650.258	27395.32	Probably Hg [D_{11}, 2]=3650.31 (K. R.)
"	2	3	3643.227	27448.19	C_{13}
"	3	6	3634.586	27513.45	C_{14}
"	3	6	3632.766	27527.23	C_{15}
"	5	6	3606.677	27726.35	C_{16}
"	1	2	3599.822	27779.15	A_{20}
"	2	3	3572.416	27992.26	A_{22}
"	4	4	3567.789	28028.56	
"	3	4	3564.423	28055.03	B_{17} and D_{13}
"	3	4	3563.362	28063.39	B_{18}
E. V.	—	5	3560.15	28088.70	B_{19} From the white spectrum of E. V. (2)
K.	1	3	3559.601	28093.04	Stronger in the blue spectrum of E. V.
"	2	3	3556.135	28120.42	D_{14}
"	5	4	3554.435	28133.87	D_{15}
"	1	—	3545.947	28201.21	A_{23} Not seen by E. and V.
"	1	1	3514.513	28453.44	Stronger in the blue spectrum of E. V.
"	1		3509.934	28490.56	Only seen in the blue spectrum by E. V.
"	2	2	3506.650	28517.25	
"	1	3	3493.435	28625.12	B_{20}
"	1	1	3476.894	28761.30	Stronger in the blue spectrum of E. V.
"	3	4	3461.192	28891.78	C_{19}
"	1	1	3455.076	28942.92	
"	1	1	3442.640	29047.48	B_{23}
"	1	2	3406.287	29357.48	
"	1	—	3398.016	29428 94	C_{20} Not seen by E. and V.
"	3	4	3393.848	29465.08	D_{17}
"	2	3	3392.885	29473.44	D_{18}
"	1	1	3389.955	29498.92	D_{19}
"	1	—	3388.464	29511.90	Only seen in the blue spect'm by E. V.
"	1	2	3387.698	29518.57	C_{21}
"	1	2	3381.573	29572.04	
"	2	3	3373.586	29642.05	C_{22}
"	1	—	3360.146	29760.61	Not seen by E. and V.
"	1	—	3341.637	29925.45	Probably Hg [S_1, 3]=3341.70 (K. R.)
"	2	2	3325.626	30069.53	
"	3	2	3319.459	30125.39	D_{21}
"	1	—	3303.08	30274.77	Probably Na [P_2, 2]=3303.07 (K. R.)
"	3	—	3302.50	30280.09	Probably Na [P_1, 2]=3302.47 (K. R.)
"	2	—	3295.44	30344.96	Not seen by E. and V.
"	1		3244.51	30820.92	Not seen by E. and V.
"	1	—	3175.11	31494.97	Not seen by E. and V.
"	2	—	3131.90	31929.50	Probably Hg [D_{23}, 2]=3131.94(K. R.)
"	4	—	3125.70	31992.83	Probably Hg [D_{22}, 2]=3125.78(K. R.)
"	4	4	3021.52	33095.93	Probably Hg [D_{11}, 3]=3021.64(K. R.)
"	1	—	2972.60	33640.58	Not seen by E. and V.
"	2	—	2968.39	33688.30	Not seen by E. and V.
"	5	5	2967.35	33700.10	Probably Hg [D_{33}, 2]=2967.37(K. R.)

nine undoubtedly belong to the spectrum of mercury and two to sodium. Only two of these lines are given by Eder and Valenta. To the blue spectrum we can ascribe with great probability seven lines, which were seen by Eder and Valenta in this spectrum only, or at least appeared there in their greatest intensity. Further four lines are met with not observed by Eder and Valenta, of which three at all events may be ascribed to "ghosts" of adjacent strong lines. Determinations in the spectra of other orders ought to show the same absolute distances between the "ghosts" and the principal lines, but with wave lengths proportionally changed. In the blue spectrum it appears that Kayser has inserted about forty of these "ghosts" as real lines. They follow the rule $\Delta\lambda = \pm K\frac{\lambda}{N}$, $\Delta\lambda$ being the difference in wave-length from the principal line of wave-length λ, N the order of spectrum, and K a constant. In the present case $K = 0.001\,N$. Kayser has seven lines more of intensities 1 and 2, not seen by Eder and Valenta, so that of the ninety-five lines there remain but seven, which have been observed in both the investigations referred to without being inserted in Table II or otherwise accounted for. Of these the line 4200.799 is the most remarkable as probably the strongest line in the red spectrum, its intensity, according to Kayser, being 9, while Eder and Valenta call it 10. If this line, as is asserted by Eder and Valenta, has nothing to do with the spectrum of nitrogen, it will possibly form the first component of a term of a compound double line, as is often the case with the strongest lines in the line spectra hitherto examined. Of the rest only the line 3567.789 has the intensity 4; the others are weak lines of intensities 1 or 2. The lines cited from Eder and Valenta are obtained in such a way that the wave-numbers for the gaps in the grouping of lines in Table II have been computed and the corresponding wave lengths sought for in the blue spectrum of Kayser and in the tables of Eder and Valenta. In the first mentioned spectrum none of the missing lines have been found, but four lines from the red spectrum of Eder and Valenta and two lines from the white

TABLE II.

LINES OF CONSTANT DIFFERENCES IN THE RED SPECTRUM OF ARGON.

No.	A	Diff. 846.47	B = A + 846.47	Diff. 803.21	C = A + 1649.68	Diff. 607.03	D = A + 2256.71
1	4 (5) 21265.27	846.94	3 (6) 22112.21	1649.64	1 (4) 22914.91	2256.79	3 (6) 23522.06
2	3 (8) 21604.70	......	....	1649.77	6 (10) 23254.47	2256.86	5 (5) 23861.56
3	3 (8) 21757.08	846.44	((1) 22603.52)	1649.49	6 (10) 23406.57	2256.51	5 (9) 24013.59
4	((5) 21789.34)	......	....	1649.49	5 (10) 23438.83	2256.51	9 (10) 24045.85
5	5 (10) 22168.77	......	....	1649.63	5 (10) 23818.40	....	....
6	4 (10) 23013.25	846.48	5 (10) 23859.73	1649.71	2 (5) 24662.96	....	....
7	4 (8) 23065.44	846.55	5 (9) 23911.99	1650.16	2 (6) 24715.60	2256.74	6 (10) 25322.18
8	6 (6) 23074.90	846.37	((2) 23921.27)	1649.64	7 (10) 24724.54	2256.66	4 (5) 25331.56
9	7 (10) 23476.98	......	....	1649.85	((2) 25126.83)	....	....
10	((3) 24794.76)	845.84	1 (4) 25640.60	1650.05	2 (4) 26444.81	2257.22	1 (2) 27051.98
11	....	......	....	....	1 (2) 26486.73	(606.19)	2 (4) 27092.92
12	2 (5) 25675.29	846.81	3 (4) 26522.10	1649.86	2 (3) 27325.15	....	....
13	....	......	....	....	2 (3) 27448.19	(606.84)	3 (4) 28055.03
14	1 (2) 25864.17	846.60	1 (1) 26710.77	1649.28	3 (6) 27513.45	2256.25	2 (3) 28120.42
15	....	......	....	....	3 (6) 27527.23	(606.64)	5 (4) 28133.87
16	4 (6) 26077.20	......	....	1649.15	5 (6) 27726.35	....	....
17	1 (2) 27208.27	846.76	3 (4) 28055.03	....	....	2256.81	(3) 4 29465.08
18	....	......	3 (4) 28063.39	....	....	(1410.05)	(2) 3 29473.44
19	2 (4) 27242.14	846.56	((5) 28088.70)	1649.64	3 (4) 28891.78	2256.78	(1) 1 29498.92
20	1 (2) 27779.15	845.97	1 (3) 28625.12	1649.79	1 (–) 29428.94	....	....
21	....	......	....	....	1 (2) 29518.57	(606.82)	3 (2) 30125.39
22	2 (3) 27992.26	......	....	1649.79	2 (3) 29642.05	....	....
23	1 (–) 28201.21	846.27	1 (1) 29047.48	....	....	....	....

spectrum have been included in Table II, where they are inclosed in brackets. The accordance of the last two lines is perhaps only accidental.

4. After thus accounting for the lines examined, we pass to Table II, which contains the wave-numbers of the above-mentioned lines arranged in such a way that lines belonging to corresponding columns (A–D) in all the rows (1–23) show the same differences. These differences are given to the left of each of the succeeding columns as referred to the corresponding line of the first; if such a line is wanting they refer to one of the following columns. The figures given before the wave-numbers indicate the intensity; for example, 4 (5) signifies that the intensity of the line is 4 according to Kayser and 5 according to Eder and Valenta.

The great number of closely accordant differences speaks well for the given arrangement of the lines as well as for the precision of the determinations. Of course it is not impossible that a few of the lines fit into their places only by chance, but in general there can be no doubt as to the reality of the connections shown in the table.

The wave-numbers of the lines in the succeeding columns are given through the relations

$$\begin{aligned} B &= A + 846.47, \\ C &= A + 1649.68, \\ D &= A + 2256.71. \end{aligned}$$

The other differences which occur are

$$\begin{aligned} C - B &= 803.21, \\ D - B &= 1410.24, \\ D - C &= 607.03. \end{aligned}$$

In seven rows four lines are known, in six others the number of lines is three, and in the remaining ten we have only two. The B-column seems to possess the least mean intensity as well as the least number of lines, but no simple regularity as to the intensity has yet been found, the maxima and minima of the rows occurring in any column. According to analogy from the com-

pound triplets in the simpler line-spectra, we may expect that some of the gaps are real ones, while others are more likely to depend upon the feeble intensity of the lines. I have not succeeded in finding anything like the well-known series of the line-spectra already arranged, and I am inclined to believe that we have to do with a new class, or, perhaps better, a new subdivision of spectra which ought to have close relations to the others, but, no doubt, are much more complicated. These spectra seem to occur in all elements at higher temperatures than those hitherto employed in such work, as, for instance, generally in spark-spectra, but also in the arc-spectra of many elements.

Certain regularities in the red spectrum of argon, whether real or accidental I would not venture to say, ought not to be passed without mention. The rows 3 and 5 give approximately the same difference as 7 and 9, viz., 411.57 and, moreover, the rows 3 and 7 are followed by adjacent rows 4 and 8, forming in this way two groups of lines of analogous constitution. The double rows 10–11, 12–13, 14–15, and 20–21, are suggestively similar, and recall the compound triplets of several elements, a row A, B, C, D, or A, B, C being accompanied by an adjacent short row, C, D.

5. But whatever opinion we may entertain regarding these regularities and the general constitution of the class of spectra in question, it results as an indisputable consequence of the foregoing investigation, that *the red spectrum of argon belongs to one single element*. Moreover, there seems to be no reason to doubt that the blue spectrum belongs to the same element, but corresponds to a higher temperature. In order to give a definite proof it will, of course, be necessary to arrange also the blue and the white spectra of argon, and then to demonstrate the connection between all the spectra of the gas. As to the supposed displacement of a great number of the lines of the white spectrum toward the red end of the spectrum, nothing seems to indicate that we have to do with a *continuous* displacement, but rather with the appearance of new lines on the red side of

those of the other spectra, with which they ought to be closely related. In such a case it seems most probable that the interesting observation of Eder and Valenta depends on a change in the relative intensity of two sets of connected lines.

LUND, August 15, 1897.

SPECTRA OF BRIGHT SOUTHERN STARS.

By Edward C. Pickering.

A detailed description of the spectra of the stars brighter than the fifth magnitude, and north of declination $-30°$, by Miss A. C. Maury, and forming part of the Henry Draper Memorial, will be found in the *Annals of the Harvard College Observatory*, Vol. XXVIII, Part I. A similar discussion of the bright stars south of declination $-30°$ is now being made by Miss A. J. Cannon, and will be published in Part II of the same volume. Meanwhile, in order to furnish astronomers with a general classification of the spectra of the southern stars the annexed table has been prepared by Miss Cannon. It contains all stars south of declination $-30°$, whose photometric magnitude is 3.50 or brighter. The designation of the star is given in the first column. The second column contains the number in the *Southern Meridian Photometry*, taken from Vol. XXXIV, Table XIII, of the Harvard Observatory *Annals*, where the identification with various other catalogues is also given. The approximate right ascension and declination for 1900 and the photometric magnitude are given in the next three columns. The seventh column contains the class of spectrum. The classification here given is that employed in the *Draper Catalogue*, the letters A, G, M, N, and O indicating stars of the first, second, third, fourth, and fifth types respectively. The letter B denotes a star of the first type, in which the Orion lines are present and nearly as intense as the hydrogen lines. The letter F denotes a star of the first type in which the hydrogen lines are rather faint and the line K is strong. The letter K denotes a spectrum intermediate between the second and third types as indicated by sudden changes in intensity. The types B, A, F, G, K, and M, therefore, indicate divisions in a continuous sequence, in which there are many subdivisions. Intermediate spectra are indicated by two letters and a number giving the position esti-

BRIGHT SOUTHERN STARS.

	S. M. P.	R. A. 1900	S. Dec. 1900	Phot. Mag.	Class
β Hydri	57	0h 20m.5	77 49	2.89	G
α Phoenicis	59	21 .3	42 51	2.45	K
β Phoenicis	187	1 1 .6	47 15	3.39	G 8 K
γ Phoenicis	257	24 .0	43 50	3.32	K 5 M
α Eridani	290	34 .0	57 44	0.51	B 3 A
α Hydri	356	55 .6	62 4	2.96	A 5 F
θ Eridani	584	2 54 .5	40 42	3.13	A 2 F
γ Hydri	779	3 48 .8	74 33	3.12	M
α Reticuli	868	4 13 .1	62 43	3.35	G 5 K
α Columbae	1217	5 36 .0	34 8	2.74	Q
β Columbae	1284	47 .5	35 49	3.06	K
ζ Canis Majoris	1444	6 16 .5	30 2	3.25	B 3 A
α Carinae	1480	21 .8	52 39	-0.96	F
ν Puppis	1569	34 .7	43 6	3.23	B 8 A
α Pictoris	1650	47 .2	61 50	3.29	A 4 F
τ Puppis	1653	47 .4	50 30	2.76	K
π Puppis	1845	7 13 .6	36 55	2.49	K 5 M
σ Puppis	1951	26 .1	43 6	2.99	K 5 M
c Puppis	2075	41 .7	37 44	3.40	K 5 M
ζ Puppis	2248	8 0 .1	39 43	2.33	Q
γ Velorum	2305	6 .5	47 2	1.91	O
ε Carinae	2441	20 .4	59 11	1.74	Q
δ Velorum	2623	8 42 .0	54 20	2.00	A
λ Velorum	2777	9 4 .3	43 2	2.10	K 5 M
β Carinae	2844	12 .1	69 18	1.73	A
ι Carinae	2868	14 .4	58 51	2.24	F
κ Velorum	2911	19 .0	54 35	2.59	B 3 A
N Velorum	2996	28 .2	56 30	2.98	K 5 M
ν Carinae	3095	44 .6	64 37	2.99	A 5 F
q Carinae	3293	10 13 .7	60 50	3.42	K 5 M
θ Carinae	3470	39 .4	63 52	3.01	B 2 A
μ Velorum	3495	42 .5	48 54	2.81	G 5 K
λ Centauri	3883	11 31 .1	62 28	3.31	B 9 A
δ Centauri	4093	12 3 .2	50 10	2.81	Q
δ Crucis	4134	9 .8	58 11	3.08	B 3 A
α Crucis	4208	21 .1	62 32	1.02	B 2 A
γ Crucis	4242	25 .6	56 33	1.55	M
α Muscae	4270	31 .3	68 35	2.91	B 3 A
γ Centauri	4294	36 .0	48 24	2.30	A
β Muscae	4312	40 .1	67 33	3.26	B 3 A
β Crucis	4324	41 .8	59 8	1.49	B 2 A
ι Centauri	4507	13 15 .0	36 11	2.08	A 2 F
ε Centauri	4610	33 .6	52 58	2.58	B 2 A
μ Centauri	4676	13 43 .6	41 59	3.33	Q
ζ Centauri	4715	49 .3	46 47	2.81	B 2 A
β Centauri	4753	56 .7	59 53	0.83	B 2 A
θ Centauri	4775	14 0 .8	35 52	2.19	K
η Centauri	4941	29 .2	41 43	2.54	B 3 A
α¹ Centauri	4960	32 .8	60 25	0.50	G
α² Centauri	4961	32 .8	60 25	1.75	K 5 M
α Circini	4969	34 .4	64 33	3.37	A 5 F
α Lupi	4975	35 .2	46 57	2.46	B 2 A
β Lupi	5081	52 .0	42 44	2.74	B 2 A
κ Centauri	5085	52 .6	41 42	3.36	B 3 A
ζ Lupi	5163	15 5 .1	51 43	3.46	K

	S. M. P.	R. A. 1900	S. Dec. 1900	Phot. Mag.	Class
γ Triang. Aust.	5194	15h 9m.6	68 19	3.00	A
δ Lupi	5220	14 .8	40 18	3.37	B 2 A
ϕ^1 Lupi	5230	15 .5	35 54	3.28	K 5 M
γ Lupi	5310	28 .5	40 50	2.96	B 3 A
β Triang. Aust.	5416	46 .4	63 7	3.09	F
α Triang. Aust.	5752	16h 38 .0	68 51	1.89	K 2 M
ϵ Scorpii	5787	43 .7	34 7	2.29	K
μ^1 Scorpii	5794	45 .1	37 53	3.26	Q
ζ Aræ	5837	50 .4	55 50	3.02	K 5 M
η Scorpii	5930	17 5 .0	43 6	3.37	F 2 G
β Aræ	6020	17 17 .0	55 27	2.72	K 2 M
γ Aræ	6021	17 .0	56 17	3.42	B
ν Scorpii	6063	24 .0	37 13	2.84	B 2 A
α Aræ	6064	24 .1	49 47	2.86	Q
λ Scorpii	6082	26 .8	37 2	1.79	B 3 A
θ Scorpii	6104	30 .1	42 56	1.99	F
κ Scorpii	6154	35 .5	38 59	2.59	B 2 A
ι^1 Scorpii	6191	40 .5	40 6	3.10	F 5 G
G Scorpii	6204	43 .0	37 1	3.22	K 2 M
γ Sagittarii	6341	59 .4	30 25	3.02	K
η Sagittarii	6428	18 10 .9	36 48	2.96	M
ϵ Sagittarii	6471	17 .6	34 25	1.93	A
ζ Sagittarii	6686	56 .3	30 1	2.69	A 2 F
α Pavonis	7074	20 17 .7	57 3	2.05	B 3 A
α Indi	7126	30 .6	47 39	3.20	G 5 K
γ Gruis	7432	21 47 .9	37 50	3.20	B 8 A
α Gruis	7481	22 1 .9	47 27	1.92	B 8 A
α Tucanæ	7524	11 .6	60 46	2.90	K 2 M
β Gruis	7615	36 .7	47 24	2.09	M
α Piscis Aust.	7684	52 .1	30 9	1.27	A 3 F

mated in tenths of the interval between them; thus B 8 A denotes that the spectrum is between B and A and closely approaches A. The spectra of nearly all the stars in the table can be thus described. For the remainder the letter Q is inserted, and the peculiarities of the spectra are described in the following remarks.

REMARKS.

θ Eridani. The presence of the line K in the spectrum may be due to the fainter component.

γ Hydri. Spectrum like that of α Orionis.

α Columbæ. Spectrum B 8 A, except that $H\beta$ consists of a narrow bright line superposed on a broad dark band.

π Puppis. $H\beta$, $H\gamma$, and $H\delta$ are stronger than in α Tauri, the typical star of this class.

ζ Puppis. The spectrum of this star contains two bright bands at wave-lengths 4633 and 4688, and a rhythmical series of lines falling between the well-known lines of hydrogen. See Harvard College Observatory *Circular* No. 16.

γ Velorum. This is the only bright star having a spectrum of the fifth type.

ϵ Carinæ. Composite type. Spectrum K, except that the line K is barely seen, and the hydrogen lines are strong. Perhaps the star is double, the fainter component having a spectrum of Class A.

δ Centauri. B 3 A, except that $H\beta$ consists of a strong bright line, $H\gamma$ of a bright line superposed on a broad dark band, and $H\delta$ of a narrow bright line superposed on a faint dark band. The presence of additional dark lines, as in other stars of this class, is well shown in this spectrum.

α Crucis. The lines are broad and ill defined, and the photographs do not show the spectra of the two components separately.

γ Crucis. Spectrum like that of α Orionis.

μ Centauri. Spectrum B 2 A. Like δ Centauri, except that $H\epsilon$ is also bright.

μ^1 Scorpii. Spectrum B 3 A. Spectroscopic binary. Period 1.4462 days.

α Aræ. Spectrum B 3 A, except that $H\beta$ is bright.

η Sagittarii. Spectrum like that of α Herculis.

β Gruis. Spectrum like that of α Herculis.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., October 8, 1897.

Minor Contributions and Notes.

THE DEDICATION OF THE YERKES OBSERVATORY.

The astronomical and astrophysical conferences held in connection with the dedication of the Yerkes Observatory were opened on Monday, October 18, at 2:30 P.M. in the Observatory library. Professor Hale announced that the afternoon session would be devoted to the fourth annual meeting of the Board of Editors of the Astrophysical Journal, at which the visiting men of science were invited to be present. Professor Pickering then took the chair. A communication from Professor Schuster,[1] regarding the mode of printing maps of spectra and tables of wave-lengths, was presented.

A general discussion followed the reading of this communication. The views of several members of the Board have already been printed in the Astrophysical Journal. They were considered at some length, and expressions of opinion were also invited from the astronomers and physicists who were attending the conferences held in connection with the dedication of the Observatory. Professor Runge thought that the mode of printing tables and the mode of printing maps were two distinct questions. The occurrence of line series in the spectra of the elements had an important bearing on the first question. In a table beginning with short wave-lengths the uncertain lines are at the top, which is an inconvenience. In the lower spectrum the lines are not doubtful. On the other hand, it is generally more convenient to have the numerical values in a table increase towards the bottom. A map can easily be turned end for end when it is necessary to compare it with another printed in the reverse direction. He did not think the subject an important one, was prepared to accept a decision in favor of either method, but thought harm was done by making a rule.

After some further discussion the following resolution was adopted: *Resolved:* That the Editorial Board adhere to the present practice of beginning tables with the short wave-lengths and of printing maps of the spectrum with the red end on the right, except in cases where a

[1]To be published in a subsequent number of this Journal.

wish to the contrary is expressed by the author of any contributed paper. It was also resolved that an announcement of this decision should be printed in the standing notice in each number of the JOURNAL.

Professor Schuster's suggestion regarding the position of the decimal point in wave-numbers (the number given being the number of wave-lengths in the centimeter) was generally approved. A discussion of a scale of intensity brought out the fact that all present were in favor of representing increasing intensities by increasing numbers. It was felt, however, that the time had not yet come to adopt a uniform scale of intensity, applicable to all classes of spectra.

The meeting annually held by the Board of Editors for the discussion of current investigations was merged in the general sessions of the conferences. The first paper presented was by Sir William and Lady Huggins, and dealt with some of the results obtained in their recent photographic studies of stellar spectra.[1] At the conclusion of the discussion of this paper the meeting adjourned.

The evening was partly cloudy, and it was consequently impossible to carry out the full programme of work with the forty-inch telescope, which included demonstrations by Professor Wadsworth of the application of interference methods to astronomical and astrophysical measurements, and observations of double stars by Professor Burnham. It was nevertheless found possible to show a few double stars after the adjournment of the second session of the conferences, at which Professor Pickering gave an account, illustrated by photographs and diagrams, of the variable star work of the Harvard Observatory.

The third session of the conferences was opened on Tuesday at 9:00 A.M., with Professor Runge in the chair. Professor Crew described his investigations of the flame of the rotating arc, which persists for an appreciable time after the current has been cut off. Photographs of the arc, taken under various conditions were exhibited. Professor Comstock followed with an account of recent work at the Washburn Observatory, including determinations of stellar parallax and investigations of the lunar atmosphere. He also exhibited a Steinheil double-image micrometer. At the conclusion of the discussion of this paper the meeting adjourned to the large dome, where Professor Hale and Mr. Ellerman exhibited various solar phenomena with the forty-inch telescope and solar spectroscope.

[1] See page 322. It is expected that the other papers presented at the conferences will be published in full or in part in subsequent numbers of this JOURNAL.

The afternoon session was called to order at 3:00 P.M., Professor Runge in the chair. Professor Hale gave an address on the aim of the Yerkes Observatory.[1] The meeting then adjourned to the laboratories and shops, where various demonstrations were made. In the optical laboratory Mr. Carl Lundin, of Alvan Clark & Sons, showed the method employed by his firm in testing telescope objectives. Professor Wadsworth exhibited in the adjoining spectroscopic laboratory an interferometer designed for the measurement of wave-lengths in infra-red metallic spectra. Professor Crew showed his rotating metallic arc in the physical laboratory, and exhibited its spectrum with a large plane grating spectroscope. The ten-foot focus concave grating was mounted in the adjoining room. In the northeast dome Professor Lord exhibited the stellar spectrograph of the Emerson McMillin Observatory, attached to the twelve-inch equatorial. Both the instrument and optical shops were in operation. In the former Mr. Lorenz showed a large heliostat and a mounting for a two-foot reflector in process of construction. Mr. Kathan exhibited the parts of a spectroheliograph which he is building for the forty-inch telescope. Mr. Mors showed a partly completed ruling-machine for optical gratings, and explained Rowland's method of grinding a perfect screw. He also exhibited a device for cutting a very long and perfect nut to exactly match a corresponding screw. In the optical shop Mr. Ritchey demonstrated the operation of a large grinding-machine carrying a five-foot glass disk for a speculum, and tested a two-foot mirror by Foucault's method. It had been expected that Dr. Humphreys would demonstrate with the concave grating the effect of pressure on wave-length. But unfortunately the pressure arc, which had been kindly loaned for the occasion by the Johns Hopkins University, did not reach the Observatory until after the conclusion of the conferences.

In the evening the sky was overcast, and a session of the conferences was substituted for the proposed observations with the forty-inch telescope. Professor Runge was in the chair. Professor Keeler exhibited with an electric lantern, kindly loaned for the occasion by the Colt Co., some photographs of the spectra of stars of the third type recently made at the Allegheny Observatory. Professor Lord followed with a talk on the stellar spectrographic work of the Emerson McMillin Observatory, with lantern illustrations. The next paper was by Pro-

[1] See page 309.

fessor Wadsworth, on the application of diffraction phenomena to astronomical and astrophysical measurements. At the close of the discussion it was announced that as the sky had partly cleared, Professor Barnard would exhibit nebulæ with the forty-inch telescope. Later in the evening the Board of Editors of the ASTROPHYSICAL JOURNAL held a special meeting.

On Wednesday the conference was called to order at 10:00 A.M., with Professor Rees in the chair. Professor Runge gave his reasons for supposing oxygen to be present in the Sun, and stated that Mr. Jewell had withdrawn his objections to the evidence previously offered. Dr. Humphreys exhibited a large number of original negatives taken at the Johns Hopkins University for the purpose of measuring the shifts of spectral lines due to pressure. Professor Doolittle gave an account of the latitude work of the Flower Observatory. The last paper of the session was by Professor Rees on the variation of latitude and the reduction of the Rutherfurd photographs. All the papers were fully discussed.

The afternoon session was called to order at 3:00 P.M. by Professor Van Vleck. Father Hedrick spoke on the photochronograph, and exhibited the instrument used at the Georgetown College Observatory, together with photographs obtained with it. Professor Pritchett spoke on personal equation in longitude determinations, giving the results of his own extensive observations. Professor Poor described a new form of mirror for reflecting telescopes, and sketched a convenient style of mounting for it. Professor Newcomb discussed the problem of determining the distribution of the stars, and dwelt upon the great importance of measuring with the spectroscope the motion of the solar system in space. Father Hagen described his forthcoming atlas of variable stars, specimen sheets of which were exhibited. Professor Myers concluded the afternoon session with a paper on the system of β Lyrae As usual, the papers were fully discussed.

As the evening was cloudy the sessions were continued, with Professor Van Vleck in the chair. Mr. Verkes had come out from Chicago on the afternoon train, and was present when Professor Barnard gave an account of his work in astronomical photography, illustrated with lantern slides. The only other paper of the evening was by Professor Pickering, who continued his illustrated description of the work of the Harvard Observatory.

The final session of the conferences was opened by Professor

Harkness on Thursday at 9:30 A.M. Dr. Laves presented a paper giving his theoretical researches on the minor planet 334. After the discussion Professor Hale described his solar investigations, and showed a number of lantern slides. The last paper was by Professor Wadsworth, on a photographic meridian circle. At its conclusion the conference adjourned. Additional papers had been presented by Professors Riccò, Safford, Very and Hull, but time did not permit them to be read.

The Trustees, members of the Faculties and guests of the University, numbering about 700, arrived from Chicago at noon, on two special trains kindly furnished for the occasion by the Chicago & North Western Railway Co. The dedicatory exercises were held in the great tower, where a platform for the speakers and chairs for the guests had been provided on the rising floor, which stood in its lowest position. The programme of the exercises was as follows:

1. The Invocation. Dean Eri B. Hulbert.
2. Music. The Spiering Quartette.
3. Address: "The Importance of Astrophysical Research and the Relation of Astrophysics to other Physical Sciences." Professor James E. Keeler, Sc.D., Director of the Allegheny Observatory.
4. Music. The Spiering Quartette.
5. Presentation. Mr. Charles T. Yerkes.
6. Acceptance on behalf of the Trustees. The President of the Board of Trustees, Mr. Martin A. Ryerson.
7. Address on behalf of the Faculties. The President of the University.
8. Prayer. Rev. James D. Butler.

Professor Keeler's address is given on another page.[1] Mr. Yerkes' remarks were as follows:

"Mr. President, Ladies and Gentlemen:

"After five years of patient waiting and incessant labor, we are brought together to perform the agreeable duty which has been in our minds during the whole of that period, namely, the dedication of this Observatory.

"It was in October of 1892 that Dr. Harper and Professor Hale arranged for the manufacture of the telescope and building the Observatory, and since that time the work has been incessant. Before this, however, three years had been spent in preparing the rough glass, making eight years in all which was required to produce what we now

[1] See page 271.

have before us. The anxiety of those who were so deeply interested in the work can scarcely be imagined, for as they followed it step by step from its incipiency to its finish, many doubts and fears naturally crossed their minds. As no glass had ever been made of the size of this there was no criterion to go by, and it was necessary to leave everything to the future. Then again, there was the risk of accident, and when the glass was safely lodged in its final resting place, the hearts of many who are now present beat much more freely and with greater satisfaction than they had since the projecting of the work. A priceless gem to these gentlemen was at last in safety, and when we consider what would have been the result in case of accident — six years of sincere work being thrown away and six years more would surely elapse before the same results could be obtained — we can imagine something of their feelings of satisfaction when they saw the final accomplishment of their labors. That we have done a good deed and one which will revert to our satisfaction we have no doubt.

"The science of astronomy, while being the oldest extant, has been, we may say, the most neglected. It is in no way commercial, and that may be one of the chief reasons. Its promulgation has always been confined to a class of enthusiasts who felt an interest in their work and gloried in the achievements which they attained.

"Five thousand years ago astronomy was studied, but it was not until six hundred years before the Christian era that any progress had been made in it. Greek mythology used it as a romance, with but little idea of its truthfulness, and up to the beginning of the seventeenth century, when the telescope was invented by Hans Lipperhay and applied by the great Galileo, but little was known of the science. From that time on through the work of Newton, Lagrange, Laplace, Dominicus Cassini, Flamsteed, Bradley, Herschel, Bessel, and others equally celebrated, good progress was made, and during the last half century there have been greater advances than ever before. This is owing to the fact that we now have the ability to determine correctly by instruments which are late inventions, matters that were never dreamed of. It is to the great telescopes that the ardent workers look for encouragement for their labors. Accurate means have been devised for recording the observations, while the photographic plate, together with the spectroscope, have been applied with the most astonishing results.

"As I said, one reason why the science of astronomy has not more

helpers, is on account of its being entirely uncommercial. There is nothing of moneyed value to be gained by the devotee to astronomy; there is nothing that he can sell. Compared with electricity and other sciences of like character, there is the greatest difference; consequently, the devotee of astronomy has as his only reward the satisfaction which comes to him in the glory of the work which he does, and the results which he accomplishes.

"These are some of the reasons why you are gathered here today and why this edifice and its contents have been erected.

"That the work will produce good results, I am, after a thorough examination, fully satisfied, and my satisfaction is still more intense when I learn of the great and enthusiastic men which the University of Chicago has gathered around it for the purpose of taking charge of the work to be performed in this Observatory. I therefore with the fullest feeling of satisfaction and pleasure, turn over to you this structure with all its contents, feeling satisfied that it is now in the best of hands, and that the labors here will be serious, conscientious, and thoroughly done. I feel that in your attempts to pierce the mysteries of the universe which are spread before you by our great Creator, the enthusiasm of your natures will carry you to success."

Mr. Ryerson expressed the thanks of the Board of Trustees to Mr. Yerkes for his gift, and dwelt upon the satisfaction they felt in the fact that the University would now be able to make further contributions to knowledge. "While recognizing fully the great practical services which astronomy has rendered to the world, I still feel that its proudest claim to recognition and appreciation must dwell in its tendency to establish and maintain in the feelings of mankind the conviction that, amid the services of science, the increase of knowledge for the sake of knowledge is not the least." In his address on behalf of the Faculties, President Harper reviewed the events in the history of the Observatory since its inception in 1892. In recounting the various gifts that have been received, he made the first public announcement of the recent gift, by that generous patron of astronomy, Miss Catherine Bruce, of $7000 for a ten-inch photographic telescope, with building and dome. He concluded by tendering to Mr. Yerkes the appreciative thanks of the Faculties of the University.[1] A very cordial letter sent for the occasion by Professor Vogel, together with congratulatory cablegrams

[1] The addresses of Mr. Ryerson and President Harper are given in full in the UNIVERSITY RECORD for October 22, 1897.

from the Vatican Observatory, Professors Tacchini, Geelmuyden, Josef and Jan Fric, Schuster and others were received.

At the conclusion of the exercises luncheon was served to the University's guests, after which an opportunity was given them to inspect the Observatory. The return to Chicago was made at 4:00 P.M.

On Friday, October 22, the visiting men of science assembled at the Ryerson Physical Laboratory of the University of Chicago, where Professors Michelson and Stratton conducted them through the building, and showed a number of interesting experiments. Among the instruments exhibited were a large interferential comparer for the production of standards of length, and a new form of harmonic analyzer. The effect of a magnetic field on radiation was beautifully shown with the aid of an interferometer.

At 1:00 P.M. the visiting men of science and other guests were entertained at luncheon by the President of the University. At 3:00 P.M. a large audience assembled in Kent Theater, where Professor Newcomb delivered his address on "Aspects of American Astronomy."[1] At the conclusion of the address Professor Hale said a few words of thanks to the men of science and official representatives of institutions for their presence at the various exercises held in connection with the dedication.

A 7:00 P.M. Mr. Yerkes gave a banquet at Kinsley's Restaurant to the visiting men of science. Toasts were responded to by Mr. Ferdinand Peck of the Board of Trustees, Professor Pickering, Professor Rees, Mr. Brashear, Professor Comstock, Professor Harkness, Professor Michelson and Professor Hale. In response to a general call, Mr. Yerkes made a few concluding remarks, in which he expressed his great satisfaction at the kindly interest in the welfare of the Observatory which had been manifested by the visiting men of science.

A list of the astronomers, astrophysicists and physicists who took part in the conferences is given below. It should be added that M. Deslandres of the Paris Observatory, and Professor Schuster of Victoria University, Manchester, visited the Observatory with the intention of taking part in the exercises, but were unable to remain, owing to the postponement of the dedication.

Professor E. E. Barnard, Yerkes Observatory, Williams Bay, Wis.

Professor N. E. Bennett, Wilmington College Observatory, Wilmington, Ohio.

[1] See page 289.

Mr. John A. Brashear, Allegheny Pa.

Mr. William R. Brooks, The Observatory, Geneva, N. Y.

Professor S. W. Burnham, Yerkes Observatory, Williams Bay, Wis.

Professor Hugh L. Callendar, McGill University, Montreal, Canada.

Mr. E. Colbert, Chicago, Ill.

Professor W. H. Collins, Haverford College Observatory, Haverford, Pa.

Professor George C. Comstock, Washburn Observatory, Madison, Wis.

Professor Henry Crew, Northwestern University, Evanston, Ill.

Professor S. J. Cunningham, Swarthmore College Observatory, Swarthmore, Pa.

Professor C. L. Doolittle, Flower Observatory, Philadelphia, Pa.

Mr. Ferdinand Ellerman, Yerkes Observatory, Williams Bay, Wis.

Mr. A. S. Flint, Washburn Observatory, Madison, Wis.

Professor Edwin B. Frost, Shattuck Observatory, Hanover, N. H.

Miss Caroline E. Furness, Vassar College Observatory, Poughkeepsie, N. Y.

Rev. J. G. Hagen, S.J., Georgetown College Observatory, Georgetown, D. C.

Professor George E. Hale, Yerkes Observatory, Williams Bay, Wis.

Professor Asaph Hall. Jr., Detroit Observatory, Ann Arbor, Mich.

Professor William Harkness, United States Naval Observatory, Washington, D. C.

Rev. John T. Hedrick, S.J., Georgetown College Observatory, Georgetown, D. C.

Professor G. W. Hough, Dearborn Observatory, Evanston, Ill.

Professor G. F. Hull, Colby University, Waterville, Me.

Dr. W. J. Humphreys, University of Virginia, Charlottesville, Va.

Professor Leslie H. Ingham, Kenyon College, Gambier, Ohio.

Professor James E. Keeler, Allegheny Observatory, Allegheny, Pa.

Dr. Kurt Laves, University of Chicago, Chicago.

Professor F. P. Leavenworth, University of Minnesota, Minneapolis, Minn.

Professor H. C. Lord, Emerson McMillin Observatory, Columbus, O.

Mr. Carl A. R. Lundin, Cambridge, Mass.

Professor C. H. McLeod, McGill University, Montreal, Canada.

Mr. F. R. Moulton, University of Chicago, Chicago.

Professor E. Miller, Kansas State Normal University, Lawrence, Kan.

Professor G. W. Myers, University of Illinois Observatory, Champaign, Ill.

Professor Simon Newcomb, Washington, D. C.

Professor E. F. Nichols, Colgate University, Hamilton, N. Y.

Mr. John A. Parkhurst, Private Observatory, Marengo, Ill.

Professor Henry M. Paul, U. S. Naval Observatory, Washington, D. C.

Professor W. W. Payne, Goodsell Observatory, Northfield, Minn.

Professor E. C. Pickering, Harvard College Observatory, Cambridge, Mass.

Professor Charles Lane Poor, Johns Hopkins University, Baltimore, Md.

Professor H. S. Pritchett, Superintendent U. S. Coast Survey, Washington, D. C.

Rev. A. W. Quimby, Private Observatory, Berwyn, Pa.

Professor J. K. Rees, Columbia University Observatory, New York City.

Mr. G. W. Ritchey, Yerkes Observatory, Williams Bay, Wis.

Mr. Charles H. Rockwell, The Observatory, Tarrytown, N. Y.

Professor Carl Runge, Technische Hochschule, Hannover, Germany.

Mr. Frederick H. Sears, University of California, Berkeley, Cal.

Professor B. W. Snow, University of Wisconsin, Madison, Wis.

Professor M. B. Snyder, Central High School Observatory, Philadelphia, Pa.

Professor C. D. Swezey, University of Nebraska, Lincoln, Neb.

Professor Milton Updegraff, Laws Observatory, Columbia, Mo.

Professor Winslow Upton, Ladd Observatory, Providence, R. I.

Professor J. M. Van Vleck, Wesleyan University, Middletown, Conn.

Professor Frank W. Very, Ladd Observatory, Providence, R. I.

Professor F. L. O. Wadsworth, Yerkes Observatory, Williams Bay, Wis.

Professor Mary W. Whitney, Vassar College Observatory, Poughkeepsie, N. Y.

Many other well-known men of science, who were unable to take part in the conferences, were present at the dedication exercises.

G. E. H.

ON THE VARIATIONS OBSERVED IN THE SPECTRUM OF THE ORION NEBULA.

In the current volume of the *Vierteljahrsschrift der Astronomische Gesellschaft*. pp. 51–52. Dr. J. Scheiner has paid his compliments to my spectroscopic observations, the *raison d'etre* of his blanket criticism seeming to lie in the fact that he and I differ as to the spectrum of the Orion Nebula.

In 1868 and later Sir William Huggins suspected that there were "small differences of relative brilliancy" of the three principal bright lines in the spectrum of different portions of the Orion Nebula; but he dismissed the subject with the statement that he did not have "sufficient evidence on these points."

Professor Vogel wrote in 1871: "An investigation of the different parts of the nebula gave the results that the three lines were everywhere present and that their relative intensities remained always constant."

In 1893 I found that the relative intensities of the three principal lines vary enormously in different parts of the Orion Nebula. In the region of the Trapezium the $H\beta$ line is the faintest of the three, but in many of the faint regions on the southwest border of the nebula the $H\beta$ line was found to be the brightest of the three, and in the region surrounding Bond's star No. 734 the $H\beta$ line was found to be many times as intense as the line $\lambda 5007$.

Dr. Scheiner in the above mentioned article states that he has observed the spectrum of the Orion Nebula under favorable circumstances, and has found no appreciable variations.

I have thought it best to ask some of my colleagues kindly to observe the spectrum with reference to the disputed points, and their results are published herewith.

Inasmuch as an efficient spectroscope is a most important item in the make-up of "favorable circumstances," I publish the constants for the apparatus used in the observations made here. The telescope has aperture 36 inches and focal length 694 inches. The collimator is 20½ inches long, the view telescope 10½ inches, the eyepiece magnifies 13 diameters, and the prism is a very dense 60° flint. The apparatus as a whole is very efficient for the purpose employed. Moderately high dispersion is advisable since it reduces the intensity of the continuous spectrum without reducing the intensity of the bright lines.

Will Dr. Scheiner kindly publish the constants of his apparatus in order that others may judge of his "favorable circumstances?" Again, did Dr. Scheiner see the bright lines in the region surrounding star Bond No. 734? If so, I respectfully ask that he publish his estimate of their relative intensities without delay. If he did not see them, his observations are either incomplete or his apparatus was too inefficient to bear on this problem.

Perhaps I may say that a large telescope is of some advantage in this problem, but it is not a necessity.

W. W. CAMPBELL.

LICK OBSERVATORY,
September 8, 1897.

OBSERVATIONS OF THE SPECTRUM OF THE ORION NEBULA.

OWING to the unscientific character of Dr. Scheiner's criticism of Professor Campbell's spectroscopic work at the Lick Observatory, the latter gentleman justly considers it necessary to call in witnesses to verify his observations on the Orion Nebula, the only specific case mentioned by Dr. Scheiner.

My notes on the spectrum, as seen by me on the morning of September 8, 1897 with the 36-inch refractor, are as follows: (1) Central part of the nebula, Trapezium region. The three nebular lines, which I shall call *a*, *b*, and *c* (*a* being the one toward the red) are all conspicuous. Middle line *b* occulted by a coarse micrometer wire, and line *a* now appears three or four times as bright as *c*. Micrometer wire now moved so as to completely cover *a*, line *b* appears just a trifle brighter than *c*. (2) Region northeast of Trapezium. Nebular line *c* faint but plainly seen, but both *a* and *b* are invisible. To identify the line that was visible, the heavy micrometer wire was moved until it was just tangent to the line on the side toward the invisible lines *a* and *b*. Then by moving the whole telescope the region of the Trapezium was brought into the field of view, and the line *c* was found to coincide in position with the only nebular line that was visible in the region northeast of the Trapezium. (3) Region southwest of the Trapezium. All three nebular lines plainly visible. Line *a* occulted with the heavy micrometer wire: the line *c* is now unmistakably brighter than *b*.

Further observations on the faint outlying portions of the nebula

were stopped by the approach of dawn. The ones here described were all easily made, and showed plainly the large variations in the relative intensities of the bright lines in different regions of the nebula.

All lovers of fair play will regret that the pages of our society's publication,— the *Vierteljahrsschrift*,— should be marred by personal attacks, the foundation for the same resting, as it seems to me, simply on the unsupported opinion of the attacking party.

J. M. SCHAEBERLE.

LICK OBSERVATORY,
September 8, 1897.

VARIATIONS IN THE SPECTRUM OF THE ORION NEBULA.

THIS morning, at Mr. Campbell's request, I estimated the relative intensities of the three bright lines λ 4861, 4959, and 5007 in the visual spectrum of three different parts of the Orion Nebula.

In the region of the Trapezium the line λ5007 was estimated to be three times as bright as the line λ4861, the line λ4959 being covered by a heavy micrometer wire. Moving this wire to cover the brightest line λ5007, the other two were, as nearly as I could estimate, of the same intensity.

Bringing the spectrum of the region surrounding the star Bond No. 734 into the field of view, the line λ4861 was clearly seen, but the other two lines had disappeared entirely. The line that was visible was identified by the micrometer.

In the spectrum of a faint region southwest of the Trapezium, the line λ5007 being covered by the micrometer wire, the line λ4861 was very decidedly brighter than the line λ4959.

All the observations described were very easy to make.

R. G. AITKEN.

LICK OBSERVATORY,
September 8, 1897.

VARIATIONS IN THE SPECTRUM OF THE ORION NEBULA.

THIS morning, at the request of Professor Campbell, I examined the spectrum of the Orion Nebula.

In the vicinity of the Trapezium the three chief lines were very bright. A comparison of the relative intensities of λ5007 and $H\beta$ placed the former as three or four times as bright as the latter. $H\beta$ was then occulted by a coarse micrometer wire, and the slit moved to the region north following the Trapezium, in the immediate vicinity of the star Bond 734. Nothing was now visible except a faint continuous spectrum. On moving the micrometer wire, however, $H\beta$ was was easily seen, apparently the only bright line on the faint background. The line was again occulted, and the slit returned to the Trapezium region. The lines λ 5007 and 4959 shone with their original brilliancy, and $H\beta$ was found to be occulted. A comparison was now made between $H\beta$ and λ 4959. In order to eliminate effects of contrast, the chief nebular line in the Trapezium region was occulted, and λ 4959 was seen to be perceptibly brighter than $H\beta$. In the south preceding region of the nebula, which was next examined, $H\beta$ was found to be the brighter of the two.

Further observations were stopped by daylight. The observations described above were very easily secured, and indisputably show that the spectrum varies enormously for the different regions examined.

W. H. Wright.

Lick Observatory,
September 8, 1897.

NOTE ON THE LEVEL OF SUN-SPOTS.

In an interesting paper published in the October 1896 number of this Journal, Professor Frost has summarized the objections recently urged against Wilson's doctrine on the level of Sun-spots. The evidence derived from observations of the apparent width of the penumbra at various distances from the Sun's limb is so contradictory that too great reliance should not be placed upon it. On the depression side we have the observations of Wilson, supported by those of De la Rue, Stewart and Loewy, Secchi and others. Professor Riccò's recent paper[1] affords further evidence, apparently of the strongest character, in favor of this long-established view. As opposed to these results we have the contrary conclusions of Howlitt and Sidgreaves, whose observations lead them to believe that spots are convex rather than concave.

[1] "On the Level of Sun-spots and the Cause of their Darkness," this Journal, **6**, 91, August, 1897.

In endeavoring to ascribe proper weight to such contradictory results it should be noted that opposite conclusions have been drawn from observations of the same spots by different astronomers. On the whole, however, I am inclined to regard the advocates of the Wilsonian doctrine as having rather the better of the argument, particularly as the results of De la Rue, Stewart and Loewy were derived from a study of photographs.

Those who have enjoyed frequent opportunities to observe Sun-spots with suitable instruments, under atmospheric conditions sufficiently good to render visible the exquisite details recorded by Langley, will probably be inclined to favor the view of Wilson. In any case they will hardly be ready to admit that the umbra is at a higher level than the penumbra, for it cannot be doubted that the penumbral filaments overlie the umbra, and frequently unite to form bridges extending completely across it.

It must nevertheless be admitted that direct observations of spots at the limb frequently seem to tell against the Wilsonian view. As Father Sidgreaves has pointed out[1] the notches there seen and photographed are difficult to account for on the ordinary depression theory. It will presently be shown, however, that it is perhaps hardly necessary to proceed at once to the conclusion that spots are of "a mountainous rather than a cavernous form."

But the difficulty just referred to is not the most serious one that confronts the Wilsonian doctrine. Both Langley and Frost have found that the ratio of umbral radiation to that of the neighboring photosphere undoubtedly increases with the distance from the center of the Sun. We thus seem forced to conclude that the umbral region whose radiation was measured was above the level of the photosphere, and consequently subjected to less absorption.

At first sight this conclusion seems to be at variance with the idea that spots are depressions, and it has been so treated by various writers. But may we not consider spots to be hollows in comparatively small areas of the photosphere which are raised above the ordinary level? The suggestion is one which would naturally present itself, but as I have seen no mention of this view, it seems worth while to call attention to it. On this idea the cross section of a spot would have some such form as is roughly indicated in Fig. 1.

a, *a*, *a*, is the ordinary level of the photosphere ; *p*, *p*, the penumbra,

[1] *Monthly Notices*, 55, 285, 1895.

and *u* the umbra of a spot. In order to account for the results obtained by Langley and Frost it is necessary to assume that *u* is above the level *a*, *a*, *a*. We must, however, at the same time assume that the radiation of the photosphere was measured at some point outside the elevated region. In answer to an inquiry regarding this point, Professor Frost informs me that in such measures his thermopile was placed at a distance from the center of the spot amounting to some three or four diameters of the umbra. For this reason he is inclined to regard the suggestion as a plausible one. To me it seems to

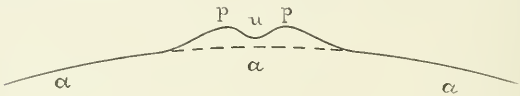


Fig. 1.

reconcile the conflicting testimony offered by the supporters of the two views. Apparent notches at the Sun's limb may be accounted for by assuming that the side of the spot nearest us is somewhat lower than the opposite penumbra. The darkening of the limb due to the smaller radiation of the penumbra might thus produce both the visual and the photographic effects. An actual notch would result from opposite depressions (lying in the line of sight) of the encircling photospheric ring. In such a case one would be likely to see a depression rather than two elevations on account of the increased effect of contrast, and also because the slope of the inner walls would probably be much sharper than that of the outer ones.

It is evident that this simple suggestion, which may very likely break down before a more searching criticism than I have yet had an opportunity to give it, can be subjected to a very definite test.[1] If measures of photospheric radiation be made close to the edge of the penumbra, we should find that the ratio umbra: photosphere *decreases* as the limb is approached. This is on the assumption that the umbra is appreciably below the bordering photosphere. It may, however, be nearly on a level with it, in which case the ratio should of course remain nearly constant at all distances from the limb.

George E. Hale.

Yerkes Observatory,
October 1897.

[1] Unless the slope of the encircling ring of photosphere is very abrupt.

NOTE ON THE PRESENCE OF VANADIUM IN RUTILE.

In the August-number of the ASTROPHYSICAL JOURNAL I find a note on the Presence of Vanadium in Rutile, in which it is stated that Professor Rowland made this discovery some four or five years ago. I was not aware of this fact when I published my paper on the chemical constitution of rutile, otherwise I would naturally have duly mentioned it. At all events my observation was thus wholly independent, The more so, as up to the present date any publication of Professor Rowland's discovery hat not come to my knowledge. As I am in possession of by far the greatest part of spectroscopic literature such a publication could only with difficulty have escaped me.

B. HASSELBERG.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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PLATE XXI.

PHOTOGRAPH OF THE "FLASH SPECTRUM," MADE WITH A PRISMATIC CAMERA BY MR. W. SHACKLETON AT THE TOTAL SOLAR ECLIPSE OF AUGUST 8, 1896.

THE

ASTROPHYSICAL JOURNAL

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VOLUME VI | DECEMBER 1897 | NUMBER 5

A SUMMARY OF THE SOLAR OBSERVATIONS MADE IN 1896 AT THE ASTROPHYSICAL OBSERVATORY OF CATANIA.

By A. Mascari.

The numerical results expressed by the following tables have been deduced from solar observations which I made in 1896. The daily statistics of Sun-spots, faculæ and prominences are given in Table I; their distribution with reference to hemisphere and latitude is given in Table II; their mean frequencies are shown in Table III. The instruments and methods used were the same as in former years.

The Sun-spots were observed during 310 days, and in this period there were eight days on which the Sun appeared without a single group of spots or pores. Their mean monthly frequency has had no regularity of occurrence; it shows the most pronounced minimum in the month of May. The same irregularity may be observed in the quarter-annual means. A comparison of these results with those of the preceding year reveals an activity inferior to that of the year 1895. The highest latitudes were reached by two small groups of pores, the one in the northern hemisphere at 22°.2 on June 21, the other in the southern hemisphere at 31°.6 on January 30 and 31. The groups of spots and pores appeared at the ordinary secondary

minimum, near the equator, with a maximum in each hemisphere between 10° and 20° heliocentric latitude. Their activity, which in the preceding year had been nearly equal in the two hemispheres, was in 1896 decidedly greater in the southern hemisphere.

The faculæ were observed on 186 days; they were never absent from the visible disk of the Sun, on each of the two hemisphères. The mean frequency for different months of the year reached its greatest value in the month of December, while the most strongly marked secondary minimum was in September. On reference to the quarter-annual means it will be seen that the mean frequency of the faculæ was decreasing in the first three quarters, and that it increased in the fourth, while for the separate hemispheres, it will be found that in the northern hemisphere the faculæ had a tendency continually to increase, while in the other hemisphere there was a decrease in the first, second, and third quarters. In general, the mean frequency of the faculæ in 1896 was greater in the northern than in the southern hemisphere, and nearly equal for each hemisphere to that of 1895, with a very slight decrease.

The distribution of the faculæ in zones of 10°, beginning at the equator, shows in each hemisphere two maxima symmetrically situated with respect to the equator, the principal one between 10° and 20° heliocentric latitude and the other, a secondary, between 70° and 80° latitude.

Again the faculæ present a secondary minimum at the equator and at the poles, and another larger one in the two hemispheres in the same zone ± 50° to ± 60°, that is to say, the conditions were nearly the same as in 1895.

The principal maximum of the faculæ falls in the same zone with the maximum of groups of spots and pores, just as in the preceding year 1895, but there is no correspondence of the spots with the secondary polar maxima of faculæ.

The complete spectroscopic observations of the solar limb which I was able to make in 1895, and which have been used, were 232 in number, and gave the following results: greater

PLATE XXII

RELATIVE FREQUENCY AND DISTRIBUTION IN LATITUDE OF FACULÆ AND PROMINENCES OBSERVED AT CANTANIA IN 1895 AND 1896.

abundance of protuberances in the northern hemisphere; number of days on which the Sun was without protuberances 9; a greater abundance in the third quarter and an increase in the mean frequency for the year 1896 compared with that for 1895 —an increase which I think is merely accidental, because there is, on the contrary, a diminution in the extent of the protuberances and in their mean elevation. The distribution of the protuberances in zones of 10° shows for the two hemispheres and for the entire year, a progressive increase in the number measured as one passes from the equator to higher latitudes, up to the zone of ± 30° ± 40°, after which there is a rapid decrease, with an absolute absence near the poles. This shows us that the zones for the maximum protuberances were different from those for the spots and faculæ, and Table III again shows that corresponding to the quarter of the year of greatest activity of the protuberances there was a maximum for the faculæ, while for both phenomena the activity was greater in the northern hemisphere—that is to say, the opposite of that which occurred with respect to the spots. With reference to the discussions engaged in by Mr. Hale and M. Deslandres on the identity of the faculæ and protuberances, I have called attention in the published summaries of my solar observations made in 1894 and 1895[1] to the discordance which exists between the distributions in latitude of the faculæ and the prominences; the observations of 1896 are also in agreement with these results.

In the accompanying figure (Plate XXII) I have illustrated the march of the two phenomena, faculæ and protuberances, in the years 1895 and 1896; the abscissæ with a + sign represent north heliocentric latitudes, while the others with the − sign represent south latitudes. The ordinates represent the mean daily frequency (expressed in thousands) for the different latitudes.

It will be seen at a glance what enormous differences there are in the curves representing the two phenomena; faculæ and prominences do not march in full accord. In the years 1895 and 1896 not only does an almost complete absence of promi-

[1] This JOURNAL, 2. 119; 4. 205.

TABLE I.

Day of the month	January					February					March					April					May					June				
	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences	Groups of spots and pores	Spots	Pores	Faculæ	Prominences
1	.	..	..		..	3	5	21	..	8	5	13	47	10	4	6	11	36	..	1	3	2	13	8	2	3	6	33		
2	4	3	15	.	3	5	5	26	11	7	6	12	54	12	2	..	..	..	..	..	2	0	24	8	0	4	5	18		3
3	4	2	15	8	4	6	9	18	.	..	7	9	58	..	..	7	14	58	..	5	1	1	29	11	2	5	4	12		
4	4	5	11	.	8	..	..	..	..	.	7	13	67	10	8	8	11	48	..	.	2	2	9	..	..	4	3	8		
5	8	2	31	.	.	..	..	..	..	..	6	17	45	.	4	8	11	30	13	4	3	4	11	13	0	4	2	7	9	
6	6	8	16		.	5	5	13	.	.	4	6	78	10	0	6	13	25	..	4	3	2	9	8	3	4	2	3	10	2
7	5	5	4		2	4	4	27		3	4	6	20	..	1	6	13	21	.	4	2	2	15	7	4	3	2	10	..	1
8	3	4	5	.	4	6	5	39	12	5	5	4	13	11	2	3	12	7	..	..	4	0	22	..	4	3	2	6	..	5
9	5	4	4		..	4	4	17	..	.	3	2	7	13	3	3	7	36	..	3	4	0	2	12	9	4	5	8	..	..
10	..	..	.		..	4	2	11	13	3	4	4	11	11	2	..	..	..	..	..	2	2	6	8	4	4	10	7	..	4
11	2	1	4	13	1	3	2	10	..	0	.	..	..	.	..	2	6	9	..	..	3	0	9	10	..	4	10	29	..	..
12	1	2	0	12	0	3	3	13	12	1	3	1	8	11	..	1	3	8	11	0	2	0	3	..	..	4	11	34	11	4
13	3	1	21	11	4	3	4	21	.	2	4	3	11	..	7	1	2	3	14	1	2	0	6	10	4	3	12	28	..	4
14	3	1	6	10	1	6	3	29	11	2	4	3	4	.	5	0	0	0	9	2	1	0	1	..	4	2	8	28	8	4
15	.		..	.	..	3	6	11	.	0	6	2	10	9	4	0	0	0	11	..	1	0	1	10	2	4	7	41	9	3
16	2	1	2	10	5	3	3	12	9	3	3	1	4	10	2	0	0	0	..	..	0	0	0	9	3	6	11	32	10	1
17	1	1	0	.	2	1	2	7	12	2	2	1	4	11	3	0	0	0	..	.	1	0	2	10	5	..	..	..	..	
18	2	2	0		2	2	3	3	13	4	..		..	..	..	1	0	1	11	1	2	0	8	9	2	3	5	13	12	6
19	2	2	3	9	5	3	4	6	15	.	.	.	..	..	..	1	2	8			1	1	7	12	4	2	1	5	13	3
20	2	2	3	11	5			.	.	.	6	4	9	..	..	3	2	24	..	4	1	2	9	11		3	2	18	10	3
21	2	2	0	10	6						5	2	13	..	0	5	1	42	15	2	2	1	11	13	3	1	3	8	10	4
22	2	2	0	9	7	.				..	5	2	35		4	6	3	27	11	3	3	1	14	13	2	3	4	13	10	5
23		.								.	5	5	34	.	4	6	2	25	15	1	3	1	9	..	7	3	5	52	15	3
24					.			.			6	3	37	15	3	3	1	23	10	2	.	.		.	..	3	8	54	12	5
25								.				.	..	..	..	4	4	13	10	4	..	..		..	..	2	8	35	7	9
26	5	3	6		.	6	16	91	14		6	7	18	..	.	4	3	22	10	1	..	..	..	..	..	2	9	22	.	
27	.		..	.	.	5	19	77	14	5	3	5	16	11	1	4	4	31	10	3	5	3	38	13	4	..	..	.		
28	5	8	17			6	16	61	..	5	3	6	12	7	8	4	2	26	..	.	5	7	37	13	..	3	5	10		
29	.	..	..		..	5	14	68	12	5	.	.	..	.	.	.			..	..	4	5	23		1	2	4	16	7	6
30	4	3	12	.			..				.		.	.		5	1	14	13	2	4	4	24	.	3	3	5	7	11	10
31	4	5	8	11	8						4	7	57	7	2						2	6	9							

TABLE I. *Continued.*

Day of Month	July: Groups of spots and pores	July: Spots	July: Pores	July: Faculæ	July: Prominences	August: Groups of spots and pores	August: Spots	August: Pores	August: Faculæ	August: Prominences	September: Groups of spots and pores	September: Spots	September: Pores	September: Faculæ	September: Prominences
1	3	4	27	13	4	1	1	3	8	..	4	4	26	9	8
2	2	4	15	11	3	2	1	11	11	5	3	4	6	13	10
3	3	4	15	..	5	1	1	4	9	7	..	..	..	..	..
4	3	5	11	10	4	2	1	3	11	8	3	3	19	13	..
5	4	5	12	10	8	2	2	5	..	3	4	2	9	11	6
6	5	5	13	10	10	1	0	5	9	3	3	2	6	..	2
7	4	3	25	9	6	0	0	0	10	3	2	3	8	10	3
8	5	4	15	10	2	0	0	0	10	3	3	4	31	10	2
9	4	3	9	10	6	2	1	2	12	5	5	9	47	8	4
10	3	3	8	7	6	2	2	3	14	4	5	19	23	..	..
11	5	2	16	9	7	2	1	2	14	3	6	18	30	7	6
12	6	2	22	9	6	4	2	3	7	5	?7	18	16	..	5
13	..	..	..	..	..	4	2	3	12	5	6	15	23	..	5
14	..	..	..	..	..	3	3	6	11	9	6	14	50	10	3
15	3	6	16	13	2	4	5	20	14	11	3	16	59	11	0
16	4	9	14	..	5	4	6	27	..	6	4	20	101	8	4
17	5	5	42	14	8	5	7	25	12	10	4	21	97	7	2
18	4	9	49	15	4	5	4	24	12	3	3	16	93	8	3
19	4	8	74	10	3	5	2	26	11	2	3	14	95	10	4
20	6	8	46	14	5	6	1	26	..	6	4	19	68	11	5
21	6	6	85	12	4	5	2	24	10	8	4	15	53	9	..
22	4	4	48	8	5	3	5	25	..	3	4	10	61	11	3
23	3	6	10	..	..	3	5	22	..	3	4	7	36	11	4
24	..	..	..	..	..	3	7	17	..	8	5	6	58	9	7
25	2	5	19	7	1	2	3	21	12	1	2	5	32	..	..
26	2	3	5	..	2	2	1	10	..	..	2	4	17	..	..
27	3	3	10	13	1	2	3	15	12	4	..	..	..	..	..
28	2	2	11	14	3	3	4	20	..	10	1	3	9	6	5
29	2	2	7	11	9	..	..	..	..	..	2	2	11	10	8
30	1	1	7	10	7	4	4	24	11	8	3	2	11	13	9
31	1	1	4	9	3	4	4	17	..	10	..	..	..	..	..

Day of Month	October: Groups of spots and pores	October: Spots	October: Pores	October: Faculæ	October: Prominences	November: Groups of spots and pores	November: Spots	November: Pores	November: Faculæ	November: Prominences	December: Groups of spots and pores	December: Spots	December: Pores	December: Faculæ	December: Prominences
1	2	3	7	13	7	3	1	14	..	..	2	4	16	13	2
2	1	1	2	..	..	..	..	..	..	..	..	..	..	..	..
3	..	..	..	..	..	..	..	..	..	..	3	6	17	..	..
4	..	..	..	..	..	2	3	13	..	..	4	7	24	..	2
5	0	0	0	13	..	2	5	14	..	..	5	9	37	14	3
6	1	1	0	12	7	..	..	..	..	..	6	6	41	..	2
7	1	1	0	10	9	..	..	..	..	..	4	8	12	..	..
8	2	1	2	10	8	4	5	26	..	..	5	9	21	..	3
9	1	1	0	9	9	..	..	..	..	..	5	8	39	19	6
10	1	1	0	7	10	7	10	38	14	1	4	6	14	..	1
11	2	1	5	7	10	7	12	44	14	3	3	8	3	..	2
12	2	1	20	11	8	6	12	34	..	1	3	2	32	12	..
13	2	0	11	8	6	5	10	21	..	2	2	3	10	..	..
14	2	1	13	..	..	7	16	33	..	..	..	..	..	..	..
15	2	0	24	9	2	5	8	39	16	3	2	6	13	..	..
16	3	3	17	..	2	..	..	..	..	..	3	4	24	15	2
17	5	6	16	..	..	4	4	11	..	..	3	4	23	12	3
18	4	7	24	12	..	4	1	21	..	..	3	7	18	15	..
19	4	12	17	..	..	1	1	0	..	..	..	..	..	..	..
20	4	9	28	..	..	1	1	6	9	6	..	..	..	..	..
21	..	..	..	..	..	4	1	12	14	7	..	..	..	..	..
22	4	5	27	..	..	3	5	13	..	..	4	9	33	..	2
23	5	6	44	..	..	..	..	..	..	..	3	6	26	..	..
24	5	9	11	..	..	..	..	..	..	..	3	4	22	..	..
25	..	..	..	..	..	2	1	14	..	..	..	..	..	..	..
26	4	3	14	..	5	2	3	15	..	..	..	..	..	..	..
27	3	3	3	..	1	2	3	11	12	2	3	7	27	..	..
28	3	2	17	12	3	3	2	16	13	7	..	..	..	..	..
29	1	2	10	..	0	2	2	11	..	3	5	7	16	13	7
30	2	3	10	11	1	..	..	..	..	..	7	6	19	12	4
31	2	2	13	13	..	..	..	..	..	..	5	6	18	..	3

TABLE II.

Heliographic Latitude		Spots: First Quarter	Spots: Second Quarter	Spots: Third Quarter	Spots: Fourth Quarter	Spots: Year 1896	Faculæ: First Quarter	Faculæ: Second Quarter	Faculæ: Third Quarter	Faculæ: Fourth Quarter	Faculæ: Year 1896	Prominences: First Quarter	Prominences: Second Quarter	Prominences: Third Quarter	Prominences: Fourth Quarter	Prominences: Year 1896
North	80 to 90	0	0	0	0	0	17	27	43	27	114	0	0	0	0	0
	70 to 80	0	0	0	0	0	22	38	74	31	105	0	0	0	1	1
	60 to 70	0	0	0	0	0	19	22	42	17	100	0	0	0	1	1
	50 to 60	0	0	0	0	0	20	19	26	8	73	4	17	26	14	61
	40 to 50	0	0	0	0	0	17	24	25	9	75	17	27	38	22	104
	30 to 40	0	0	0	0	0	25	27	31	22	105	22	39	70	17	148
	20 to 30	0	0	1	1	2	26	39	45	15	125	25	18	45	9	97
	10 to 20	15	11	11	2	37	38	54	57	37	186	17	7	21	11	56
	0 to 10	9	6	6	9	28	25	28	38	17	108	13	5	15	7	40
South	0 to 10	7	15	6	11	38	23	36	34	24	117	19	12	18	9	58
	10 to 20	27	18	25	24	90	43	69	84	36	232	16	18	20	21	75
	20 to 30	7	6	2	1	15	25	30	55	32	142	19	15	40	19	93
	30 to 40	1	0	0	0	1	18	16	18	17	69	24	21	46	20	111
	40 to 50	0	0	0	0	0	14	8	21	10	53	10	14	34	10	68
	50 to 60	0	0	0	0	0	9	13	19	9	50	5	9	19	3	36
	60 to 70	0	0	0	0	0	37	21	19	12	89	0	2	0	1	3
	70 to 80	0	0	0	0	0	26	33	35	28	122	0	0	1	0	1
	80 to 90	0	0	0	0	0	16	31	39	23	109	0	0	0	0	0

TABLE III.

1896	Mean Frequency								
	of groups of spots and pores	of spots	of pores	of faculæ			of prominences		
				in northern hemisphere	in southern hemisphere	in both hemispheres	in northern hemisphere	in southern hemisphere	in both hemispheres
January	3.43	3.00	7.96	5.64	4.73	10.36	2.35	1.59	3.94
February	4.10	6.38	27.67	6.33	6.00	12.33	1.80	1.87	3.67
March	4.64	5.52	26.08	4.73	5.80	10.53	1.48	1.81	3.29
April	3.59	4.74	19.89	5.93	5.71	11.64	1.32	1.16	2.47
May	2.36	1.64	12.54	4.95	5.45	10.40	1.86	1.41	3.27
June	3.14	5.48	19.21	6.00	4.25	10.25	2.35	1.90	4.25
July	3.54	4.36	22.68	5.79	4.96	10.75	3.22	1.56	4.78
August	2.87	2.67	13.10	6.33	4.71	11.04	3.07	2.50	5.57
September	3.75	9.82	39.11	4.95	4.82	9.77	1.83	2.87	4.70
October	2.52	3.07	12.41	4.87	5.73	10.47	2.44	3.06	5.50
November	3.62	5.05	19.33	6.43	6.71	13.14	1.80	1.70	3.50
December	3.78	6.17	21.96	7.22	6.67	13.89	1.79	1.21	3.00
First Quarter	4.07	4.94	20.52	5.50	5.55	11.05	1.85	1.75	3.60
Second Quarter	3.02	3.97	17.20	5.56	5.13	10.70	1.85	1.49	3.34
Third Quarter	3.37	5.55	24.69	5.69	4.84	10.52	2.76	2.28	5.04
Fourth Quarter	3.25	4.66	17.55	5.90	6.16	12.06	2.05	2.07	4.12
Year	3.41	4.78	20.10	5.65	5.29	10.94	2.19	1.92	4.11

nences correspond to the polar maxima of faculæ, but it will also be seen that the other two maxima of the faculæ are nearer to the equator, since they fall between $\pm$ 10° and $\pm$ 20° and the others in much higher latitudes.

As a whole, the observations of these three years agree in so satisfactory a manner as to cast doubt on the correctness of the view that the seat of the two phenomena is the same; they lead us to admit only with reserve the opinion that the faculæ are identical with protuberances.

ON THE OBSERVATION AND KINEMATIC INTERPRETATION OF THE PHENOMENA DISCOVERED BY DR. ZEEMAN.

By M. A. Cornu.

The phenomena discovered by Dr. Zeeman relating to the action of a magnetic field on the radiations emitted by various luminous sources have given rise to some confusion, which seems to me to result from the optical imperfection of the methods of observation. The following arrangements give these phenomena with great clearness and leave no doubt as to the definitive conclusions announced by the author of the discovery.[1]

The luminous source is the flame of an oxyhydrogen burner playing upon a fragment of asbestos saturated with fused sodium chloride, or an induction spark taken between two metallic electrodes; it is placed between the two poles of an electro-magnet producing an intense magnetic field.

A vertical slit placed near the luminous source, or in the plane of a focal image of this source, directs the ray upon a concave Rowland grating of ten feet focus, which produces a bright line spectrum of the source. The spontaneously reversible lines are the ones which seem to show the phenomenon to the best advantage.

FIRST ARRANGEMENT.

One of these lines is observed in the focal plane of an ocular in which a steel needle is placed normally to the spectral lines. Behind the ocular is placed a doubly refracting Wollaston prism[2] which doubles the image of the needle; the diameter of this needle, though slightly conical, is so chosen that the two images

[1] Dr. P. Zeeman, "Doublets and Triplets in the Spectrum produced by external Magnetic Forces." *Phil. Mag.*, July 1897, p. 55; September 1897, p. 255; this Journal, May 1897.

[2] A rhomboid of spar might be used in place of the Wollaston prism; but there would be certain precautions necessary to avoid the effect of parallax arising from the inequality in distance of the planes of vision of the two images.

have a common edge. We thus obtain two adjoining fields, the one polarized parallel, the other perpendicular to the spectral lines.

1. *The ray is observed normal to the magnetic lines of force.*

The two poles of the electro-magnet (Faraday coils, ordinary Ruhmkorff model), terminating in two rounded cones, can be brought together to within 8^{mm} or 10^{mm}, and the observation is made in a plane perpendicular to the horizontal line which joins them.

The doubly refracting prism is adjusted in such a way that the spectral lines exhibit no discontinuity on the line of separation of the two fields when the strength of the magnets is zero.

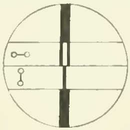


FIG. 1.

When the electro-magnet is excited the line is seen to widen; but in the two polarized fields the appearance of the line is modified. In the field where the polarization is parallel to the lines of force (line of the poles) the line is doubled, *i. e.*, a dark line appears in its center; in the other it is, on the contrary, narrower, and falls exactly on the prolongation of the dark line referred to above.[1] Reversal of the magnetic field does not affect the phenomenon in the least.

From this we may conclude that each single unpolarized line is transformed into a triplet, the exterior components of which are completely polarized parallel to the lines of force, while the central component is completely polarized in a perpendicular plane. The magnetic field thus produces two alterations of the

[1] When sodium light is used each of the lines D_1, D_2, may be more or less reversed, *i. e.*, more or less doubled: from this there results an apparent complication, but this does not affect the essential characteristics of the phenomenon.

original period, respectively equal and of contrary sign, and thus gives rise to two vibrations normal to the lines of force without modifying the period of the vibration parallel to these lines.

2. *The ray is observed parallel to the lines of force.*

One of the polar armatures is pierced in the line of the poles in order to permit the passage of the light following the direction of the lines of force. In order to make the observation, a quarter wave mica plate, the principal sections of which are at 45° with those of the prism, is placed between the ocular and the doubly refracting prism. As soon as the magnet is excited the line is seen in the two fields to become narrow and to break on the line of separation. (Fig. 2.) If the quarter wave plate is

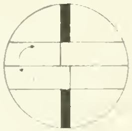


Fig. 2.

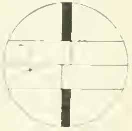


Fig. 3.

turned through 90 the displacement takes place in the opposite direction. (Fig. 3.) Reversal of the poles reverses the direction of the displacement. It is also noticed that the middle of the two lines thus produced occupies sensibly the position of the original line: the two alterations of the period are thus equal and of opposite sign.

The phenomenon is rendered more easily visible by placing side by side on the same glass plate two quarter wave plates with homologous rectangular sections; a slight to and fro motion of these plates gives alternately the two appearances mentioned above. A suitable rhythm increases still further the sensitiveness of the method; for when the eye is fixed upon the line of one of the regions the relative displacement of the corresponding line of the other region is *physiologically* doubled.

These observations prove that the action of the magnetic field separates each radiation into two rays circularly polarized

in opposite directions, the reversal of the poles reversing the directions of rotation of the circular vibrations. By determining the direction of rotation of each of these rays[1] it is possible to epitomize the various results in the very simple statement given further on.

SECOND ARRANGEMENT.

Instead of the long doubly refracting Wollaston prism (necessary in order to obtain two sufficiently broad fields) it is possible to utilize a single Nicol prism: the double field is then obtained with mica plates properly chosen and oriented.

1. *Ray observed normal to the lines of force.*

In the plane of the eyepiece are placed two half wave plates adjusted for the refrangibility of the bright line employed.[2] The upper plate has its upper section parallel or perpendicular to the direction of the spectral lines: the lower plate at $\pm 45°$ to these lines. If the principal section of the Nicol prism is parallel or perpendicular to this direction the appearance (Fig. 1) is the same as with the first arrangement, since the second half wave plate turns through 90° the planes of polarization of the rays which it transmits.

2. *Ray observed parallel to the lines of force.*

In the focal plane of the eyepiece two quarter wave plates are placed: the upper plate with its principal sections at $+45°$, the lower one at $-45°$ to the direction of the lines; the Nicol prism being adjusted as before, the same appearance (Fig. 2) as with the first arrangement is obtained.

If it is desired to produce the rhythmical motion a second

[1] The correct determination is not so easy as might be supposed: one is in danger of committing the errors which Dr. Zeeman himself recognized (*loc. cit.* p. 58). In a technical publication (*l'Éclairage électrique*) I purpose to indicate various optical methods which permit this form of determination to be made practically and verified.

[2] The accurate adjustment of the double refraction of the mica plates also requires special care, regarding which particulars will be given in the appendix already referred to.

system is arranged in reverse order, and placed opposite the first in the order shown below:

+45°	−45
45°	+45

Alternate motion of this system from right to left produces the reversal and the apparent duplication so favorable to the observation of the phenomenon.

KINEMATIC INTERPRETATION OF THE PHENOMENA.

The phenomenon as a whole can be stated in conformity with the rules of Fresnel and Ampère. These rules are as follows:

(1) A ray of ordinary light is the superposition of two independent rays equal in intensity and polarized at right angles to each other (Fresnel):

(2) A plane polarized ray is the superposition of two rays equal in intensity and polarized circularly in opposite directions (Fresnel).

(3) A magnetic line of force is equivalent to the axis of a solenoid, the south pole of which is to the left of the current (Ampère).

The action of a magnetic field on the emission of a radiation tends to decompose the rectilinear vibratory components capable of propagation by waves polarized circularly in a direction parallel to the currents of the solenoid.

The vibrations which rotate in the direction of the current of the solenoid are accelerated, those which rotate in the reverse direction are retarded.

This immediately explains the doublet observed along the lines of force. In the direction perpendicular to these lines this statement shows that the component parallel to the lines of force (wave polarized perpendicular to this direction) is unaffected: this is the central line of the triplet; the two outer lines polarized at right angles to this are more difficult to explain. However, their existence may be perceived geometrically: in fact, each

consists of two circular vibrations, one accelerated, the other retarded, in which the magnetic field doubles the component normal to the lines of force; there is mutual extinction or compensation of the two longitudinal components which cannot be propagated (the two waves polarized rectilinearly are produced by circular vibrations of opposite direction, seen in *section*).

This purely kinematical interpretation, although somewhat superficial, shows that the phenomenon discovered by Dr. Zeeman can be explained by considerations wholly independent of the electro-chemical ideas of Professor Lorentz, which are the origin of and are closely related to the vortex theories recently restored to favorable consideration.

It shows, moreover, the essential difference which exists between this phenomenon and that of the magnetic rotary power discovered by Faraday.

The action of the magnetic field on the sources where the waves are, so to speak, in a *nascent* state, affects the *period of vibration*, while in the experiment of Faraday it affects the *velocity of propagation* of luminous waves which have already acquired their permanent state.

I have convinced myself with the same arrangements, that the magnetic rotation of the plane of polarization is accompanied by no sensible variation of the vibration period of the monochromatic light employed, while I have previously demonstrated[1] that the velocity of propagation of two circular waves is modified: one is accelerated, the other is retarded, by equally sensible quantities, in the direction corresponding to Ampère's rule.

PARIS, October 1897.

[1] *C. R.*, 92, 1365; the phenomena discovered by Dr. Zeeman permit the extension of variations of period of the conjectural law there announced (*loc. cit.*, p. 1307) for the variations of the velocities of two circular waves due to the doubling of a wave of rectilinear vibration.

CORRECTIONS AND ADDITIONS TO PROFESSOR H. A. ROWLAND'S TABLE OF SOLAR SPECTRUM WAVE-LENGTHS.

The errors in wave-length have been carefully determined for the whole table, but the identification of solar lines with the lines of the elements in the spectrum of the electric arc has, at the present time, been carefully revised only from wave-length 3722 to 4175. Therefore the corrections and additions to the identifications have been given only for the more important lines between these limits. A very few small solar lines have been added to the table.

The changes in wave-length have been few, most of the changes in this table being additions to the identifications.

FIRST PART.

				Corrections and Additions		
Page [1]	Wave-length	Substance	Intensity and Character	Wave length	Substance	Intensity and Character
8				2979.410 ^{4}		0
8	2980.080		0 Nd	2980.080 ^{4}		0 Nd
8	2983.704		000 N	2983.764 ^{4}		000 N
8				2985.769 ^{4}		000
8	2988.333		000 N	2988.333 ^{4}		000 N
8	2988.873		000	2988.873 ^{3}		000
8				2989.378 ^{4}		0
9	3003.773 ^{1}	Ni	2 Nd ?	3003.773 ^{2}	-, Ni	2 Nd ?
9				3010.996 ^{1}		2 d
14	3077.295 s	Fe	3	3077.295 } s	Fe	3
14	3077.332 s		1	3077.332 } s		1
18	3138.798	Zr	1	3138.789	Zr	1
21	3177.633	Fe ?	2	3177.653	Fe ?	2
23	3195.705 s	Ni	2	3195.705 s	Y-Ni	2
23	3200.407		2 Nd ?	3200.407	Y,-	2 Nd?
23	3203.435		1	3203.435	Y	1
24	3216.807		1	3216.807	Y	1
25	3223.378		1	3223.378	Mn	1
26	3242.395		1	3242.395	Y	1

[1] The page numbers refer to the reprint of the Table, which will soon be ready for distribution.

FIRST PART—*Continued.*

				Corrections and Additions		
Page	Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
30	3286.784		0	3286.754		0
30	3289.498		4	3289.498	Eb?	4
32	3308.947		5	3308.947	Co, Ti	5
32	3309.065	Co, Ti	0000 N	3309.065		0000 N
32	3312.453	Co	2	3312.453	Ni	2
33	3328.016	Di ?	2	3328.016	Y	2
33	See note to 3335.192, 3335.350, etc.			See note to 3335.299, 3335.350, etc.		
35	3353.875		4	3353.875	Sc,-	4
37	3372.901	Ti-Pd	5	3372.901 } d?	[1] Ti-Pd	10
37	3372.994		5	3372.994 } d?		
				[1] This is probably a strong titanium line which was measured as double, but is probably a single line reversed in the Sun.		
38	3385.167		0	3385.167	Y	0
40	3407.937	Di ?	0	3407.937	Y	0
43	3443.791	Co	5 d?	3443.791	Co, Ti	5 d?
47	3496.224	Co	0	3496.224	Co, Y	0
53	3565.535 s	Fe	20	3565.535 s	Fe	12
54	3572.712	-, Sc	6	3572.712	Sc,-	6
62	3683.182	Co	3	3683.182 } s	Co	3
62	3683.229	Fe-v	4	3683.229 } s	Fe-V	4
62	3683.761		2	3683.761	Fe	2
63	3685.810		0000	3685.800		0000
63	3694.344		3	3694.344	Eb?	3
64	3706.175	Mn	6 d ?	3706.175	Ca, Mn	6 d ?

SECOND PART.

				Corrections and Additions		
Page	Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
	3722.174		2	3722.174[1]	Fe ?	2
4	3725.638		3	3725.638	Fe,-	3
4	3727.061	Mn	4d ?	3727.061	Fe, Ru-Mn	4d ?
4	3727.965		2	3727.965	Fe	2
4	3728.183		1	3728.183	Ru	2
4	3728.813	Ti-Fe	2	3728.813	Fe-Ti	2
4	3730.534	Fe	3	3730.534	Fe, Ru	3
4	3732.545 s	Ti-Fe-Co	6	3732.545 s	Co, Fe	6
5	3737.059 s	Ca-Mn	5	3737.059 s	Mn-Ca	5

[1] See remarks at the beginning of this Table.

SECOND PART—*Continued.*

				Corrections and Additions		
Page	Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5	3743.508 s	Fe	6	3743.508	Fe-Ti	6
5	3743.626	Ti	2	3743.626		2
5	3745.617	Ti	1	3745.617	-Ti	1
5	3745.717 s	Fe	8	3745.717 s	Fe	8
5	3746.058 s	Fe	6	3746.058 s	Fe	6
5	3746.191	Ni	0	3746.191	Ni	0
6	3753.732	Fe-Ti	6	3753.732	Fe-Ti	6 d ?
6	3758.269		00	3758.269		00
6	3758.375 s	Fe	15	3758.375 s	Fe	15
6	3759.215	Zr	1	3759.215	La, C	1
6	3759.297	La-Fe	2	3759.297	Fe, C	2
7	3767.493		1 N	3767.493	Ru,-	1 N
8	3787.304	Fe-C	1	3787.304	C-Fe	1
8	3788.839		2	3788.839	Y	2
9	3789.553	Fe	1 N	3789.553	Fe,-	2 N
9	3799.934	V	1	3799.934		1
9	3800.046 s		0	3800.046	V	0
10	3804.151	Fe	3	3804.151 s		3
10	3804.934	Fe-Cr C	2	3804.934	Cr-C	2
10	3807.681	Fe	6	3807.681	V-Fe	6
10	3811.945	Fe	2	3811.945		2
10	3812.033		2	3812.033	Fe	2
11	3814.671	Fe-C	4	3814.617	Co.Fe-C	4
11	3817.523	Co-Ti-C	0	3817.523	-C	0
11	3824.441		2	3824.441	Fe	2
12	3825.543		2	3825.543	Cr	2
12	3826.555		1	3826.555	Cr	1
12	3827.714		2	3827.714	Fe	2
12	3829.617	Ti-C	2	3829.617	Fe, Ti-C	2
12	3829.728	Fe-C	0	3829.728	-C	0
12	3829.822	Ti-C	1	3829.822	Mn, Ti-C	1
12	3831.002	Fe	2	3831.002	C Fe	2
12	3833.026		3 N	3833.026	-, Ni	3 N
12	3834.006	Mn C	3	3834.006	C Mn-Rh	3
12	3836.905		1	3836.905	Zr ?, Ti	1
12	3837.277		2	3837.277	Fe	2
13	3843.854		2	3843.854	Co,-	2
13	3845.606	Co-C	8 d ?	3845.606	C Co	8 d ?
13	3849.501	C ?	1 N	3849.501	C-Cr	1 N
13	3849.675		1	3849.675	Cr	1
13	3850.118	Fe	10	3850.118	Fe Cr	10
14	3852.347	Cr, C	1	3852.347	Cr, C	1
14	3855.450	V	2	3855.450	Cr, V	2
14	3855.547		1	3855.547	C,	1
14	3857.805	C ?	6 d ?	3857.805	Cr-C	6 d ?
14	3858.262		1 N	3858.262	-, Ti	1 N
14	3860.767	C-Ni	3 N	3860.767	Ni, C	3 N
15	3866.577	C	1	3866.577	C-Ti	1

SECOND PART—*Continued.*

				Corrections and Additions		
Page	Wave-length	Substance	Intensity and character	Wave-length	Substance	Intensity and character
15	3868.060	-C	2	3868.060	Fe, C	2
15	3873.065	-C	2	3873.065	Fe-C	2
16	3874.651		2	3874.651	-, Cr	2
16	3876.194	Fe	5	3876.194	Fe, V	5
16	3879.331	C	1	3879.331	Cr, C	1
16	3883.033	C	1	3883.033	C, Ti	1
16	3883.426	C-	2	3883.426	C-Fe	2
17	3884.748	Ca	1	3884.748	Co	1
17	3885.364	Fe, Cr	2	3885.364	Cr	2
17	3886.568	V	0	3886.568	La	0
17				3886.704	V	000
17	3886.942	Cr	3	3886.942	Cr, Mo	3
17	3889.374		1Nd?	3889.374	-, Ba	1Nd?
17	3890.068		1	3890.068	Nd, Ce	1
17	3890.707		1N	3890.707	Nd,-	1N
17	3891.918		0	3891.918	Ba	0
17	3892.069	Fe	4	3892.069	Cr, Fe	4
17	3894.165	Cr	3	3894.165	Fe, Cr, V?	3
18	3900.681	T - Fe-Zr	5	3900.681	Ti-Fe	5
18	3902.002		3	3902.002	Nd-	3
18	3902.114	Fe	1	3902.114		1
18	3903.090	Fe, Cr	10	3903.090	Cr,-Fe, Mo	10
18	3903.302		1	3903.302	Cr	1
18	3903.398		2	3903.398	V-Ce?	2
18				3904.310	V	000
18	3905.017		1	3905.017	Mn,-	1
18	3905.146		1	3905.146	Mn-	1
18	3906.044		3	3906.044	Nd,-	3N
18	3907.807		1	3907.807	Fe, Ti?	1
18	3907.910		1	3907.910	Cr, Nd	1
18	3909.976	Fe	5	3909.976	Fe, V	5
18	3910.079	Co-Ca	3Nd?	3910.079	Ba, Co	3Nd?
19	3913.609	Ti-Fe	5d?	3913.609	Ti-	5d?
19	3921.105		0	3921.105	Nd	0
19	3921.188	Cr-Nd	3	3921.188	Cr-	3
19	3921.855	Zr-Mn	4	3921.855	Ce, Mn-Zr	4
19	3923.180		1	3923.180	Pt, Ce	1
20	3925.347 s	Co, Fe?	4	3925.347 s	Co, Fe?-V	4
20	3928 357	Cr?	2Nd?	3928.357	-, Mn	2Nd?
20	3929.363	Fe-La-Mn	2	3929.363	Fe-La-Mn-Co	2
20	3929.497	Co?	1	3929.497		1
20	3933.523		8N	3933.523		[1]8N
20	3934.108	Co-	8N	3934.108	Co, V-Zr	[1]8N
20	3934.174		0N	3934.508	Ti, Cr?	0N
20	3938.439		2	3938.439	-, Cr	2
20				[1] Mostly shading of K.		
21	3941.323		1	3941.323	Cr, V	1
21	3941.637	Cr	3	3941.637	Cr, Nd	3
21	3941.997		1	3941.997	-Mn	1

SECOND PART *Continued.*

				Corrections and Additions		
Page	Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
21	3942.157	Mn?-	0N	3942.157	V-	0N
21	3943.721		1	3943.721	V,-	1
21	3948.818	Ti	4	3948.818	Ti, V	4
21	3951.219	Cr	1	3951.219	Cr, Nd	1
21	3952.103	Mn-	2	3952.103	Mn, V	[1]2
21	3952.342	Na?	0	3952.342	Nd	0
21	3952.754	Fe	4	3952.754	Ce-Fe	4
21	3952.894		0	3952.894	Mn, Nd?	0
21	3953.043	Mn	3	3953.043		3
21				[1] This V line weak in V Cl from Tromsdorff.		
22	3955.524		00	3955.624		00
22	3956.476	Co,-Ti	4	3956.476	Ce, Co-Ti	[1]4
22	3958.355	Ti, Zr	5	3958.355	Zr, Ti, Ce	5
22	3959.972		1	3959.972	Ce,-	1
22	3964.663	Fe	3	3964.663	Ce Fe	3
22	3964.897	Fe?	0 Nd?	3964.897		0 Nd?
22	3966.647	Ni, Fe	2	3966.647		2
22	3966.778	Fe	3	3966.778	Fe, Zr	3
22	3968.350		6 N	3968.350	-,Zr	[2]6 N
22	3968.854	Fe?	1 N	3968.854		1 N
22				[1] Ce and Co a faint side line.		
22				[2] Mostly shading of H.		
23	3968.886		6 N	3968.886		[2]6 N
23	3970.419		1	3970.419	Fe?	1
23	3970.540		2	3970.540	Fe	2
23	3970.631		1	3970.631	Ni	1
23	3973.262	Co	1	3973.262		1
23	3973.796	Fe	1	3973.796	Nd, V, Fe	[3]1
23	3974.536	Fe	3	3974.536	Fe, Ni	3
23	3974.637	Ni?	2	3974.637		2
23	3975.506	Co-	1	3975.506	Rh-Co, V?	1
23	3977.009	Fe	2	3977.009	Nd-Fe	2
23	3978.809	Co, Cr	3	3978.809	Co-Cr, Ce	3
23	3979.664	,-Co	4	3979.664	Nd-Co	4
23				[2] Mostly shading of H.		
23				[3] V line weak in V Cl.		
24	3981.662		00	3981.662	-,Zr?	00
24	3981.762	Zr?	0	3981.762		0
24	3982.630	Ti-Mn	2	3982.630	Ti	2
24	3982.742	V	3	3982.742	Mn-V	3
24	3983.341		2 N	3983.341	-,Cr	2 N
24	3985.385		0	3985.385	Mn	0
24	3985.463	Mn	1	3985.463		1
24	3985.539	Fe	5	3985.539	Fe	3
24	3986.321	Fe	3	3986.321	Fe Nd	3
24	3988.114		0	3988.114	Eb?	[2]0
24	3990.120	Cr-Mn	1	3990.120	Mn-Cr	1
24	3991.690	Co	0	3991.690	Co-Mn	0

SECOND PART—*Continued.*

				Additions and Corrections		
Page	Wave-lengths	Substance	Intensity and Character	Wave-lengths	Substance	Intensity and Character
24	3991.830	Co-Cr	2	3991.830	Cr, Co	2
24	3992.538	Fe	1	3992.538	Fe, Ce	1
24	3994.092	Cr	1	3994.092	Ni?	1
24	3994.160	Ni	1	3994.160	Cr	1
24				[2] There is a strong metallic line at 3988.140, which is supposed to be due to erbium, but it is probably not coincident with the solar line.		
25	4001.315		3	4001.315	Mn,-	3
25	4005.202		1	4005.202	Fe	1
25	4005.632		1	4005.632	Fe	1
25	4005.856		3	4005.856	V	[1] 3
25				[1] This V line is weak in V Cl from Tromsdorff		
26	4009.694	Fe	1	4009.694		1
26	4010.327	Fe	1	4010.327	Ce-Fe	1
26	4012.541	Ti	4	4012.541	Ti, Ce	4
26	4017.620	Ni ?	2	4017.620		2
27	4021.057	Co	3	4021.057	Nd-Co	3
27	4021.893	Ti	0	4021.893	Nd	0
27	4022.018	Fe	5	4022.018	Ti-Fe-V	5 d ?
27	4023.533	Co-	3	4023.533	V, Co	[2] 3
27	4025.286	Ti-	3	4025.286	Ti-Ce	3
27	4028.497	Ti-	4	4028.497	Ti-Ce	4
27	4028.912	Fe-Ce	1	4028.912	Fe	1
27	4030.646	Fe-Ti	5	4030.646	Nd Fe-Ti	5
27	4030.878	Mn	4	4030.878		
27	(4030.918) s		[1]	(4030.918) s	Mn	[3] 10 d ?
27	4030.947	Mn	5	4030.947		
27	4031.048		2	4031.048	Fe ?	2
27	4031.865	Fe-La	2	4031.865	La,-	2
27	4031.942	Mn	2	4031.942	Fe?, Nd, Mn,V	2
27	4033.224 s	Fe-Mn	[1] 7 d ?	4033.224 s	Mn	[3] 8 d ?
27	4033.337		1	4033.337	Fe ?	1
27				[2] V line weak in V Cl from Tromsdorff.		
27				[3] Apparent duplicity caused by reversal in Sun.		
28	4034.644 s	Mn-Fe	[1] 6 d ?	4034.644 s	Mn	[2] 6 d
28	4036.923		1	4036.923	V,-	1
28	4037.837		1	4037.837	Ce,-	1
28	4043.839		0	4043.839	Cr	0
28	4043.956	Cr	0	4043.956	Ti	0
28	4044.644		1	4044.644	-, Zr	1
28	4045.371	Mn	1 N	4045.371	Ce, Mn	1 N
28	4045.748		2	4045.748	, Zr, W?	2
28	4047.338	K ?	00 Nd ?	4047.338	-K	00 d
28	4047.461	Fe	2	4047.461	Ce-Fe	2
28	4048.224		1 N	4048.224	Cr-	1 N

SECOND PART — *Continued.*

Page	Wave-length	Substance	Intensity and Character	Corrections and Additions: Wave-length	Substance	Intensity and Character
28				[2]Apparent duplicity caused by reversal in Sun.		
29	4049.822		1 Nd ?	4049.882	-, Cr	1 Nd ?
	4052.603	Mn	2	4052.603	Mn, Fe	2
	4052.650	Fe	3	4052.650		3
	4053.981	Fe-Ti	3	4053.981	Cr-Fe-Ti	3
	4054.962		2	4054.962	Fe	2
	4055.189	Ti-Fe	3	4055.189	Ce-Ti-Fe,Zr	3
	4058.372	Co-Fe	4	4058.372	Ti, Co-Fe	4
29	4061.881	Mn	[1] } 2 Nd	4061.781	Mn	[1] 2 Nd
29	4062.105		} 2	4062.105		2
30	4064.361	Ti	1	4064.361	Zr-Ti	1
30	4067.139	Fe	5	4067.139	Cr-Fe	5
30				4068.555	Cr	000
30	4069.761		1	4069.761	V,-	1
30	4071.680	Fe	1	4071.680	Fe, V	1
30	4072.295		00 N	4072.295	, V?	[2] 00 N
30	4073.921 s	Fe	4	4073.921	Ce, Fe	4
30	4078.515	Fe	4	4078.515	Zr-Fe	4
30				[2] This line is probably variable in the solar spectrum.		
31	4080.368	Fe, Nd	3	4080.368	Fe, Nd, Cr	3
31	4081.415	Fe	1	4081.415		1
31	4083.095	Mn	4	4083.095	V-Mn	4
31				4084.300	Cr	000
31	4085.408		1	4085.408	-, Ce	1
31	4086.133		1	4086.133	Fe?	1
31	4091.109		3	4091.109	Ce-	3
31	4092.547	Co, Mn	3	4092.547	Co, Mn, V	3
31	4092.821	[1] V, Ca	3 d?	4092.821	[1] V, Ca	3 d?
31				[1] These lines coincide with the heads of bands due to calcium. The bands probably become lines owing to the weak dilution of calcium vapor in the Sun.		
32	4096.262	Fe	2	4096.262	Fe, Nd	2
32	4098.689	[1] Ca?	4	4098.689		4
32	4098.740		2	4098.746	[1] -, Co?	2
32				4101.531		000
32	4101.840		3	4101.840	Fe?	3
32				4105.010	Cr	000
32	4107.649 s	Ce-Fe-Zr	5	4107.649 s	Ce-Fe	5
32	4109.905	[1] V	2	4109.905	V	[2] 2
32				[2] One of the strongest Vanadium lines.		
33	4111.021	Mn	1	4111.021	-, Mn	1
33	4111.154	Mn?	1	4111.154		1
33	4116.707	[1] V	0	4116.707	V, Fe?	0
33	4116.859	Nd?	1	4116.859		1
33	4116.974		00	4116.974	Nd?	00

SECOND PART *Continued.*

Page	Wave-length	Substance	Intensity and Character	Corrections and Additions: Wave-length	Substance	Intensity and Character
33	4119 550	Fe	1	4119.550	C?-Fe-V	1
33	4123.384	[2] La	12	4123.384	[2] La	1
33	4123.539	V	0	4123.539	Cr	0
33	4123.664	Mn	1	4123.664	Ce, V-Mn	1
34	4126.200	V	000	4126.200		000
34	4126.344	Fe	4	4126.344	V-Fe	4
34	4127.957	Fe	4	4127.957	Ce-Fe	4
34	4128.251	V-	6 d	4128.251	Ce-V,-	6 d
34	4131.271	Mn	1	4131.271	Ce, Mn	1
34	4132.235	Fe	10	4132.235	Fe-Co	10
34	4134.589	V-Fe?	3	4134.589	Fe?	3
34	4134.675		1	4134.675	V	1
35	4137.809	Fe, Ce	1	4137.809	Ce	1
35	4140.400	Fe?	0	4140.400		0
35	4140.558		3	4140.558	-, Fe?	3
	4141.809	La	0	4141.809	-, La	0 N
				4141.910	La	0000
35	4143.664		2	4143.664	-, Mo	2
35	4147.645	Mn	1	4147.645		1
35	4147.677		000	4147.677	Mn	00
35	4149.360	Zr	2	4149.360	C, Zr	2
36	4150.964	Ce	00N	4150.964		00N
36	4151.129	Zr, Ti	1	4151.129	Ce-Zr, Ti	1
36	4152.108	Fe, La	2	4152.108	Fe, La, Ce	2
36	4152.242	Ce?	1	4152.242		1
36	4154.265		2	4154.265	-, Fe ?	2
36	4162.623		1N	4162.623	C, -	1N
37	4162.825		1N	4162.825	Ce, C	1N
37	4163.818	Ti, Cr	4	4163.818	Cr-Ti,-	4
37	4165.550	Fe	3d ?	4165.550	C, Fe	3d
37	4165.759	Ce,-	2	4165.759	-, Ce	1
37	4167.737		1Nd ?	4167.737	V-Ru ?	1Nd ?
37	4168.025		2	4168.025	Ce-Fe	2
37	4168.133	Ni	2	4168.133	Ni, C	2
37	4171.854 [1]	Cr, La, Mn, Ni, Fe	2	4171.854	C, Fe ?	2
37	4172.211	Al ?	1	4172.211	Al	1
37	4172.296	Fe	2	4172.296	Fe-Ce	2
37	[1] Probably due to some common impurity of unknown origin. Is it Al? or Si? The gallium line is also in this region, but I have no specimen of gallium with which to determine its exact position. The Fe line is strong enough alone to account for it.			[2] Note at bottom of page 37 should be struck out. The line is mostly if not wholly due to carbon (or cyanogen).		
38	4177.698	Fe	3	4177.698		3
38	4177.772		3	4177.772	Fe*	3
40	4207.566	Fe	1N	4207.566	C	1N

*See remarks at the beginning of this Table.

SECOND PART — *Concluded.*

				Corrections and Additions		
Page	Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
41	4233.328	Mn-Fe	4	4233.328	Mn	4
42	4239.890	Mn	3	4239.890	Fe, Mn	3
42	4246.996	Y?	5	4246.996	[1] Sc	
				[1] One of the strongest lines in the spectrum of scandium.		
45	4280.027		1	4280.027	Fe,-	1
45	4280.374		1	4280.374	, Fe	1N
45	4285.966		1	4285.966	Co	1
45	4288.310	Ti	1	4288.310	Ti, Fe	1
46	4299.803	Ti	2	4299.803	Fe, Ti	2
46	4304.729		2	4304.729	Fe,-	2
56	4455.980	Mn	2	4455.980 } s	Mn	2
56	4456.064 s	Ca	3	4456.064 }	Ca	3
56	4459.525	Fe, Cr	1	4459.525	Cr	1
57	4464.938		1	4464.938	Fe	1
58	4482.338	-, Fe	5	4482.338	Fe,-	5
59	4497.023 s	Cr	3	4497.023 } s	Cr	3
59	4497.138	Zr	0	4497.138 }	Zr	0
59	4501.448	Ti,-	5	4501.445	Ti,	5
62	4546.129	Fe, Cr	3	4546.129	Cr	3
80	4914.150		2	4914.150	Ni	2
81	4934.214 } s	Ba	3	4934.214 } s	Ba-Fe ?	6
81	4934.277 }		4	4934.277 }		
				[1] This is probably a barium line with another narrower line (probably iron) at the red edge.		
92	5209.779		0000	5209.779		0000
96	5328.696	Fe	2	5328.696	} [1] Fe	5
96	5328.696	Fe	2	5328.696	}	
				[1] Measured as double, but probably reversed in Sun.		
109	5646.039		00	5646.049		00
110	5682.427		2	5682.427	Ni	2
111	5693.330		0000	5693.350		0000
113				5754.222	A ?	000
114	5788.990	A (O)	00	5788.983	A (O)	00
114	5789.418 [1]	A (O)	od	5789.415[1]	A (O)	od
118				5889.972	A (wv)	1N
118	5896.155	Na	20	5896.155 $D_1 s^3$	Na	20
118	5896.35D7$_1$s^3		00N	5896.357		00N
120	5918.635	A (wv)	4	5918.635	A (wv)	4d
122	5974.094	N	0000	5974.094		0000N
122	5974.812	N	0000	5974.812		0000N
126	6090.429	Fe	2	6090.429	Ti, V	2
129	6252.773 s		7	6252.773 s	Fe	7
131	6298.666	Co, A (O)	2	6298.666	Ni, A (O)	2
136	6609.360 s		3	6609.360 s	Fe	3
146	7140.568	A	000N	7140.560	A	000N

RESEARCHES ON THE SPECTRUM OF THE VARIABLE STAR η AQUILÆ.

By A. Bélopolsky.

At a meeting of the Academy of Sciences of St. Petersburg, on September 27, 1895, I presented some preliminary researches on the spectrum of the star η Aquilæ, the magnitude of which lies between 3.5 and 4.7. I had found with a single prism spectrograph that the star has a periodically variable velocity in the line of sight; but the unfavorable time, the low position of the star (merid. alt. $= 30°$), and the small dispersion of the spectrograph did not allow me to carry the researches further.

This year our great refractor has a correcting lens for the chemical rays, and our two-prism spectrograph by Halle has been provided with a large collimator. These two arrangements have enabled us to obtain spectrograms of stars down to the 4.5 magnitude, without prolonging the exposure beyond one hour, so that under favorable atmospheric conditions we obtain satisfactory spectrograms of variable stars like β Lyræ, η Aquilæ and δ Cephei in all their phases of brightness.

The twelve spectrograms of the star η Aquilæ obtained during the present summer fully confirm my earlier researches concerning this star.

All the measures have been carried out with reference to the spectrum of iron, by means of a solar spectrogram, which is placed on the spectrogram of the star during the process of measurement. In this manner are obtained (1) the differences of settings on the lines of the star and of the Sun; (2) the differences ot settings on the lines of the artificial spectrum and of the Sun; (3) the differences of settings on the lines of the star and on the lines of terrestrial iron; *i. e.*, the immediate displacements.

These differences give two methods for finding the displacement of any line. It is only necessary that the line should be found in the spectrum ot the Sun, as in the case of the line

$H\gamma$. By means of these differences we construct three kinds of curves, wave-lengths being measured along the axis of x, and differences along the axis of y. The sum of the ordinates for a given line (*e. g.*, $H\gamma$) of the first two curves gives the displacement of that line. The ordinates of the third curve, for the selected ray, give the direct displacement. This method allows us to determine the displacement even of lines which are not represented by terrestrial lines in the spectrogram. It also allows us to use the line λ 4481.16 in the spectra of I type stars, where it is in most cases more easily measured than the diffuse lines of hydrogen.

The spectrum of η Aquilæ belongs to a type intermediate between II and III. Its resemblance to the spectrum of the variable star δ Cephei is remarkable.

In the measurements the following lines have been used.

λ4251	double	λ4315	good
4272	double	4319	rather wide
4308	good	4322	rather wide
4313	distinct, narrow	4384	good; narrower than in type II
4314	good	4405	the most distinct line

λ4415 broader than in spectra of type II

In the following table are given the differences d_1, of the micrometer readings for the stellar and the solar lines; also, the differences d_2 for the lines of the artificial spectrum and those of the Sun. The displacement d_3 of the $H\gamma$ line $= d_1+d^2$, where d_1 and d_2 are determined graphically by the method already described. The value of d_3 is also obtained immediately from the differences of readings on the terrestrial and stellar lines, in which case it is denoted by d_4

1897 — July 10.

λ	d_1	d_2	λ	d_1	d_2		
4272	0.450	0.268	4322	0.467		$d_1 =$	0.474
4275	0.447		4326		0.315	$d_2 =$	0.321
4308	0.469	0.291	4384	0.483	0.353	$d_3 =$	0.153
4315	0.460		4405	0.497	0.374	$d_4 =$	0.153
4319	0.474		4415		0.362		
			4427	0.488			

1897 — July 11.

λ	d_1	d_2	λ	d_1	d_2
4251	—0.528	0.327	4319	—0.507	
4272		0.348	4322	0.535	
4275	0.517		4326		0.384
4288	0.553		4384		0.414
4295	0.536	0.344	4405	0.540	0.420
4308	0.516	0.348	4415	0.513	0.405
4314	0.553		4427	0.519	

$d_1 = -0.530$
$d_2 = 0.383$
$d_3 = -0.147$
$d_4 = -0.156$

1897 — July 12.

λ	d_1	d_2	λ	d_1	d_2
4272		—0.369	4322	0.242	
4275	0.249		4326		—0.350
4308	0.238	0.371	4384		0.319
4315	0.232		4405	0.225	0.307
4319	0.246		4415	0.269	0.329

$d_1 = 0.242$
$d_2 = -0.346$
$d_3 = -0.104$
$d_4 = -0.114$

1897 — July 13.

λ	d_1	d_2	λ	d_1	d_2
4272		—0.378	4368	0.248	
4308	0.268	0.354	4370	0.221	
4315	0.255		4384		—0.301
4322	0.210		4405	0.253	0.297
4326	0.252	0.315	4415	0.291	0.319
4352	0.241		4427	0.281	

$d_1 = 0.251$
$d_2 = 0.325$
$d_3 = -0.074$
$d_4 = -0.064$

1897 — July 17.

λ	d_1	d_2	λ	d_1	d_2
4202	0.084	—0.255	4326	0.091	—0.220
4261	0.021	0.214	4384	0.096	0.205
4272	0.078	0.226	4395	0.092	
4295	0.083		4405	0.092	0.204
4808	0.100	0.239	4415	0.171	0.217
4321	0.100				

$d_1 = 0.092$
$d_2 = -0.214$
$d_3 = -0.122$
$d_4 = -0.126$

1897 — July 21.

Weak spectrogram. The lines λ 4405 and λ 4415 are distinct, and give the following values of d_4:

λ 4405 $d_4 = -0.046$
λ 4415 $d_4 = -0.036$

1897—July 22.

λ	d_1	d	λ	d_1	d		
4275		−0.114	4326		−0.124	$d_1 =$	0.127
4308		0.168	4384		0.137	$d_2 =$	−0.127
4315	0.135		4400	0.103		$d_3 =$	0.000
4319	0.111		4405	0.118	0.136	$d_4 =$	+0.010
4322	0.142		4415	0.157	0.119		
			4427	0.136			

1897—July 25 (1st meas.)

λ	d_1	d_2	λ	d_1	d_2		
4261	−0.222	0.029	4322	0.182		$d_1 =$	0.207
4272		0.019	4326		0.069	$d_2 =$	0.077
4275	0.223		4368	0.184		$d_3 =$	−0.130
4308	0.195	0.033	4384		0.102	$d_4 =$	−0.148
4313	0.207		4405	0.238			
4314	0.199		4415	0.199			

1897—July 25 (2d meas.)

λ	d_1	d_2	λ	d_1	d_2		
4272		0.034	4319	−0.216		$d_1 =$	−0.208
4308	−0.210	0.042	4326		0.075	$d_2 =$	0.076
4313	0.212		4384		0.112	$d_3 =$	−0.132
4314	0.206		4405	0.214	0.115	$d_4 =$	0.139
			4415	0.209			

1897—July 25 (2d spectrogram.)

λ	d_1	d_2	λ	d_1	d_2		
4272	0.063	−0.074	4326		−0.025	$d_1 =$	0.094
4308	0.080	−0.065	4384		+0.001	$d_2 =$	−0.027
4313	0.113		4405	0.117	+0.016	$d_3 =$	−0.121
4319	0.084		4415	0.098	+0.026	$d_4 =$	−0.125
4322	0.098						

1897—July 26.

λ	d_1	d_2	λ	d_1	d_2		
4255	−0.011	−0.117	4322	+0.031			
4280	+0.051		4326		0.088	$d_1 =$	0.004
4308		0.119	4384		0.067	$d_2 =$	0.096
4314	+0.004		4405	−0.013	0.073	$d_3 =$	−0.092
4319	−0.004		4415	0.009	0.070	$d_4 =$	−0.108

1897—July 30.

A weak spectrogram, on which, however, the following measurements could be made :

λ 4405 $d_4 = +0.025$
λ 4415 $d_4 = +0.050$

1897—August 2.

λ	d_1	d_2	λ	d_1	d_2		
4261	−0.046	−0.127	4326		−0.125	$d_1 =$	+ 0.022
4272		0.135	4371	−0.014		$d_2 =$	−0.107
4295	+0.015		4384		0.091	$d_3 =$	− 0.085
4308	+0.026	0.155	4405	0.012	0.085	$d_4 =$	− 0.110
4313	−0.005		4415	0.035	0.074		
4319	+0.027		4427	0.033			
4322	+0.028						

1897—August 13.

λ	d_1	d_2	λ	d_1	d_2		
4251	−0.237	+0.317	4371	0.350		$d_1 =$	− 0.332
4308	0.310	0.347	4384		0.413	$d_2 =$	+ 0.379
4322	0.289		4405	0.363	0.424	$d_3 =$	+ 0.057
4326	0.340	0.376	4415	0.262 ?	0.419	$d_4 =$	+ 0.050
4370	0.349						

The displacements thus found are expressed in micrometer revolutions. To find the velocities in the line of sight use was made of the following table, which contains the values of a coefficient K, obtained by measuring solar spectrograms taken at different temperatures. Instead of the temperature, however, the argument is the linear distance between the lines λ 4308 and λ 4405, expressed in revolutions of the micrometer.

Argument	K	log. K	Argument	K	log. K
29.00	30.37	1.4825	29.80	29.57	1.4709
.10	.28	.4811	.90	.47	.4694
.20	.17	.4797	30.00	.37	.4679
.30	.07	.4783	.10	.27	.4665
.40	29.97	.4768	.20	.18	.4651
.50	.88	.4754	.30	.09	.4637
.60	.77	.4738	.40	.00	.4624
.70	.67	.4724	.50	28.90	.4609

For the displacement of the line λ 4405, log K = 1.4975.

The length of the interval λ 4308—λ 4405 on the spectrograms of the star was as follows:

July 10,	30.06	July 17,	30.10	July 26,	30.08
11,	.06	22,	.11	Aug. 2,	.09
12,	.07	25.1,	.05		
13,	.07	25.2,	.05		

Performing the reductions we have the following table.[1]

No.	Pulkowa mean time			Displacement	Observed motion	Reduction to Sun	Motion relative to Sun
		d	h	r	km	km	km
1	July	10	12	0.153	− 33.3	− 4.6	28.7
2		11	12	− 0.152	− 33.0	+ 4.1	− 28.9
3		12	13	0.109	23.7	+ 3.7	− 20.0
4		13	12	0.069	− 15.0	+ 3.3	− 11.7
5		17	12	− 0.124	− 26.9	+ 1.4	25.5
6		21	12	− 0.041	− 9.1	− 0.5	9.6
7		22	12	+ 0.005	+ 1.1	0.9	+ 0.2
8		25	11	0.137	− 29.8	2.2	32.0
9		25	12	− 0.123	− 26.8	− 2.2	− 29.0
10		26	11	− 0.100	− 21.7	− 2.7	− 24.4
11		30	12	+ 0.038	+ 8.9	− 4.5	+ 4.4
12	Aug.	2	11	− 0.098	− 21.2	− 5.9	− 27.1
13		13	11	+ 0.054	+ 11.7	10.7	+ 1.0

By means of the light ephemeris given in the *Annuaire du Bureau des Longitudes* we obtain the intervals between the epoch of minimum and the times of observation, as follows:

	Int.			Int.	
July 10,	2^d	14^h	July 22,	0^d	6^h
11,	3	14	25,	3	6
12,	4	15	25,	3	7
13,	5	14	26,	4	8
17,	2	10	30,	1	2
21,	6	10	Aug. 2,	4	1
			13,	0	17

We can now draw the curve of velocities in the line of sight. Assuming that the period of revolution = $7^d\ 4^h$ we find the following elements:

[1] In conformity to the practice of this JOURNAL, the German geographical miles used by the author have been reduced to kilometers.

Motion of the system $= -1.85^{\text{km}} = -13.7^{\text{km}}$. Then[1]

$$A = 16.3^{\text{km}} \qquad A + B = 32.6^{\text{km}} \qquad 2\sqrt{AB} = 32.6^{\text{km}}$$

$$B = 16.3^{\text{km}} \qquad A - B = 0.0^{\text{km}}$$

$$z_1 = 77 \qquad z_2 + z_1 = -30$$

$$z_2 = -107 \qquad z_2 - z_1 = -184$$

$u_1 = 90^\circ.0$, point for which velocity in line of sight $= 0$

$u_2 = 270^\circ.0$

$\omega = 90^\circ.0$, longitude of periastron

$e = 0.163$

$\left(\frac{dz}{dt}\right) = 00$

$T = +2^{\text{d}}\ 0^{\text{h}}$, time of periastron passage

$a \sin i = 1\ 382\ 000^{\text{km}}$.

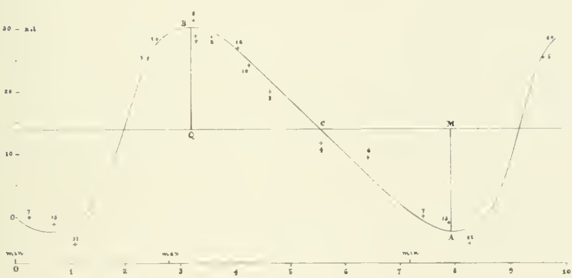


FIG. 1.

It will be seen that the times of minimum brightness and the times for which the velocity in the line of sight is zero do not coincide. For this reason the changes in the brightness of the star cannot be explained as the result of eclipses, and some other explanation must be sought. It is very remarkable that this is also true of the variable star δ Cephei. (See my researches on that subject in the *Bull. Acad. St Pétersbourg.*)[2]

[1] LEHMAN-FILHÉS, *A. N.* 3242.

[2] Also this JOURNAL, 1, 160–161, 1895.

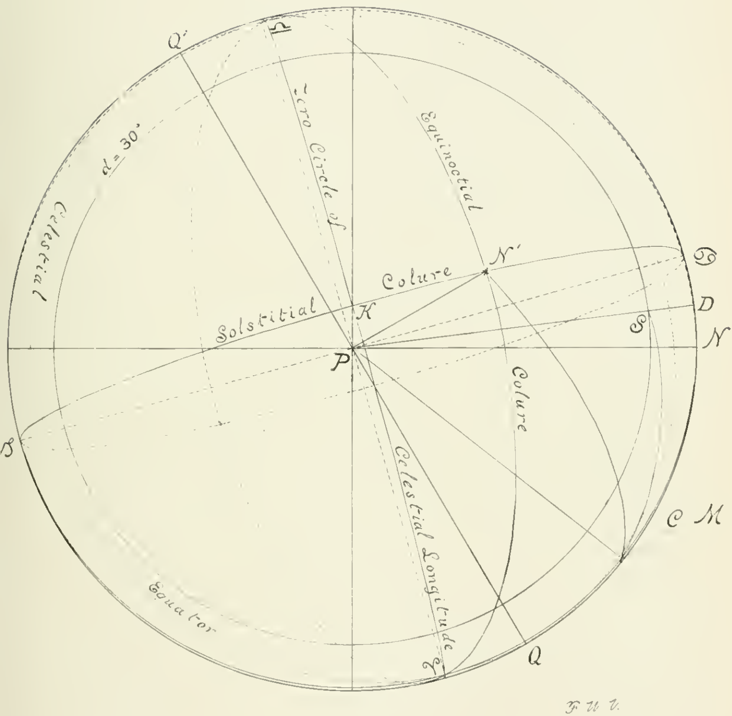
HELIOGRAPHIC POSITIONS. II.

By Frank W. Very.

In my previous article, I have given the steps by which the radius and position-angle of a Sun-spot, referred to the center of the solar image, may be obtained and freed from error. We wish to know the positions as seen from the center of the Sun, and for the further transformation of the coördinates we again employ methods devised by Mr. Carrington. The subject is one not entirely devoid of pitfalls for the unwary, as I shall show first by a reference to the *Philosophical Transactions of the Royal Society of London* for 1869 (**159**, 1–110) in which is a memoir by De La Rue, Stewart, and Loewy, entitled: "Researches on Solar Physics. Heliographical Positions and Areas of Sun-spots observed with the Kew Photoheliograph during the years 1862 and 1863." A representation of some of the leading circles of the sphere is given in an illustration (Fig 10, *loc. cit.*)[1] which does not purport to be a true orthographic projection, but a diagrammatic construction, exaggerating the angles for the sake of clearness. It is, however, incorrect. The point in it, marked N', should be on a projection of the solstitial colure through E, the ecliptic pole, and not on a great circle through the Sun's pole (P) and the solstitial points; while C, the projection of the Earth's position on the celestial sphere, must necessarily be on the ecliptic trace, and not (as there given) on a projection of the Earth's equator far from the ecliptic. Besides this, the Earth's equator and the ecliptic must intersect, not on the outer bounding circle which represents the Sun's equator, but at inner points, marked ♈ and ♎ in the correct representation which is given here (so far as I know) for the first time; and in consequence of these errors, the line representing the Earth's equator has been incorrectly drawn in the figure cited. For these reasons, and in

[1] To be compared with Plate XXIII accompanying this article.

PLATE XXIII.



Q'
Zero Circle of
Equinoctial
d = 30°
Celestial
Colure
N'
Solstitial
K
D
N
P
Colure
Celestial Longitude
C
M
Equator
Q
F. U. V.

order to show the true relations, I have substituted an exact, although composite, projection.

In Plate XXIII there is given a projection of the celestial sphere upon the plane of the Sun's equator. The poles of the Earth, Sun and ecliptic, the position of the Earth in its orbit, and various other important lines and points, are first projected radially upon the celestial sphere, and the latter is then projected orthographically upon the plane of its solar equinoctial circle. The Earth's equator intersects the Sun's equator at the points Q, Q', and the ecliptic plane meets the solar equatorial plane in the line NB.

An examination of the correct representation will also show that in the position chosen in another figure given by De La Rue,[1]

EXPLANATION OF PLATE XXIII.

Plate XXIII is an orthographic projection of the celestial sphere on the plane of the Sun's equator. The Earth is supposed to be projected in C; and S is the projection of a Sun-spot.

$N' C$ = celestia meridian through C.

$P M$ = solar meridian through C.

$d = S D$ = heliographic latitude of Sun-spot.

$\rho = S C$ = heliographic angle of Sun-spot from Earth.

$D = M C$ = heliographic latitude of the Earth.

$\chi = S C P$ = terrestrial position-angle of the Sun-spot from the Sun's north pole

$L = N M$ = heliographic longitude of the Earth from the Sun's ascending ecliptic node (N), read in the usual direction and therefore greater than 180° in the figure.

$l = N D$ = heliographic longitude of the Sun-spot from the Sun's node.

K = projection of north pole of ecliptic.

P = projection of north pole of Sun.

N' = projection of north pole of Earth.

B ♈ $C N$ (inner line) visible half of ecliptic.

$N Q' Q M$ (outer bounding circle) = solar equator in plane of projection.

Q = ascending node of Sun's equator on Earth's equator.

Q' = descending node of same. The invisible half of Earth's equator, as seen from the direction of the Sun's north polar axis produced, is shown dotted.

Arc ♈ N = 74° 22′ (year 1900 A.D.)

Arc $N Q$ = 59 54

Arc $K P$ = 7 15

Arc $K N'$ = 23 27

Arc $P N'$ = 26° 17

[1] Fig. 9, *loc. cit.*, copied, however, without alteration from a figure given by Carrington. Compare with Fig. 4, Plate XXIV, accompanying this article.

N' instead of being at the left should be at the right of P,[1] which should incline forwards towards C, the center of the solar disk, by an arc which is the foreshortened projection of CM, the semiminor axis of the equatorial ellipse. The node (N) should be at the extreme right. The opening of the elliptic projection of the Sun's equator is much exaggerated in this figure, and also in several published by Secchi, Young, and others. In fact the only exact representations of this feature which I have seen, are those of Sir Robert S. Ball in his *Story of the Sun*.

The symbols used by De La Rue, Stewart, and Loewy in their treatment of the problem of heliographic positions, are in the main the same as those of Carrington,[2] and (with trifling modifications) shall now be gathered together, for convenience of reference.

$\odot =$ celestial longitude of Sun.

$N =$ celestial longitude of the ascending node of the Sun's equator.

$= 73^\circ\ 40' +$ precession from 1850.

$I =$ inclination of Sun's equator to ecliptic.

$= 7^\circ\ 15'$ (Carrington's elements).

$\omega =$ inclination of Earth's equator to ecliptic.

$R =$ solar radius of drawing or photograph (in inches for example).

$r =$ measured distance of a Sun-spot from the center of the Sun-picture (same unit).

$r =$ same corrected for distortion.

$R'' =$ tabular value of Sun's semidiameter for the given date (from Ephemeris).

$\rho' =$ measured distance of a Sun-spot from the center of the drawing in terms of the tabular semidiameter, R''

[1] The direction in which heliographic longitude is said to be reckoned in this figure shows that it cannot be a perverted (right for left) image, and if it represented a position six months later, being then of an April date, instead of September, the points N and B would have to change places.

[2] R. C. CARRINGTON, *M. N.*, 15, 175, 1855.

ρ = heliographic (or heliocentric) angle of Sun-spot from the Earth's position.

G = angle at the Sun's center between the pole of the Earth and the pole of the ecliptic, as orthographically projected on the Sun-picture (positive when the projection of the Earth's north pole is seen east of the projection of the north pole of the ecliptic).

H = angle at the Sun's center between the pole of the Sun and the pole of the ecliptic, orthographically projected on the Sun-picture (positive when the projection of the north pole of the ecliptic is seen east of the Sun's north pole).

L = nodal heliographic longitude of the Earth, or longitude of the Earth measured along the solar equator from the ascending node of the Sun's equator on the ecliptic

D = heliographic latitude of the Earth.

P = position-angle of Sun-spot, reckoned from terrestrial north, through east (measured on Sun-drawing or photograph by a protractor, or originally at the telescope by the position-filar micrometer).

χ = $P + G + H$.

d = heliographic latitude of Sun-spot.

l = nodal heliographic longitude of Sun-spot, or longitude measured along the Sun's equator from the Sun's node as origin.

$L-l$ = heliographic longitude of Sun-spot from central meridian.

l' = heliographic longitude of adopted solar prime meridian from the Sun's node.

$L-l'$ = heliographic longitude of the center of the solar disk from the solar prime meridian.

$l-l'$ = heliographic longitude of Sun-spot from the solar prime meridian.

T = the fraction of a revolution executed by the prime meridian at a given date, expressed usually in time.

The following ten equations are sufficient for the computation of heliographic position :

(1) $$\tan G = \tan \omega \cos \odot.$$

(2) $$\tan H = \tan I \cos (\odot - N).$$

(3) $$\tan L = \cos I \tan (\odot - N).$$

(4) $$\sin D = \sin I \sin (\odot - N).$$

(5) $$\rho' = \frac{r'}{R} (R'').$$

(6) $$\rho = \sin^{-1} \frac{r'}{R} - \rho'.$$

(7) $$\sin d = \cos \rho \sin D + \sin \rho \cos D \cos \chi.$$

(8) $$\sin (L - l) = \sin \chi \sin \rho \sec d.$$

(9) $$T = \frac{t}{25.38} - m.$$

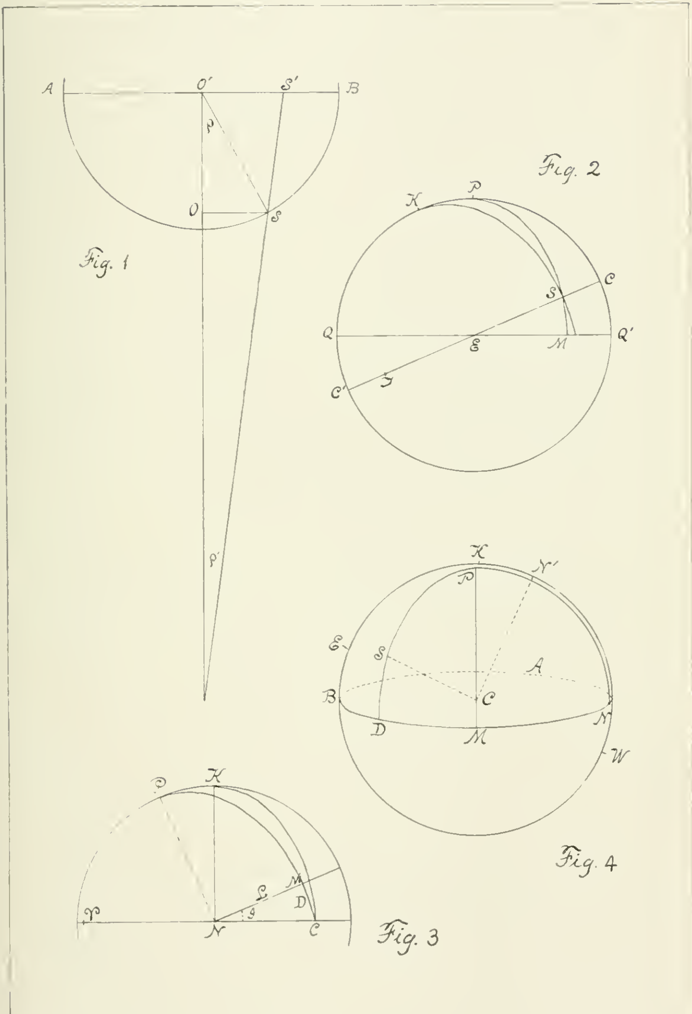
T being the remainder left after dividing the interval (t) from the epoch (or number of days between 1854.0, civil reckoning, and the date of observation) by 25.38 days, the adopted period of the Sun's sidereal rotation. The number of complete sidereal rotations of the prime meridian, which have been executed since the epoch is denoted by m.

(10) $$l' = T \times \frac{360}{25.38} = 14.1844 \cdot T.$$

These formulæ have been derived by the method of Mr. Carrington, "who by introducing tabulated auxiliary values has condensed the two steps necessary for passing from the ecliptical longitude and latitude to the heliographical into one."

We pass next to the derivation of these formulæ. In Fig. 1, Plate XXIV, AB representing the trace of a plane parallel to the plane of projection of a Sun-picture, and ASB the solar hemisphere presented towards the Earth, it is evident that the measured radial distance of the spot (S) from the center of the picture is $O'S'$ which is greater than OS, the true distance of the spot from the central line of sight ($O'O$). The measured distance must therefore be reduced in order to get OS, from which the heliocentric angle ρ may be obtained. From the figure,

PLATE XXIV.



$$\rho' = \frac{O'S'}{O'B}(R'') = \frac{r}{R}(R''),$$

approximately, and

$$\frac{r}{R} = \frac{O'S'}{O'B} = \frac{O'S'}{O'S} = \sin O'SS' = \sin(\rho + \rho'),$$

approximately,[1] or

$$\rho + \rho' = \sin^{-1}\frac{r}{R};$$

hence $$\rho = \sin^{-1}\frac{r}{R} - \rho'.$$

In Fig. 2, Plate XXIV, "let $C'EC$ represent the ecliptic, $Q'EQ$ the celestial equator, and K and P the poles of these circles. Then if S is the position of the Sun, ES will be its longitude $=$ $\odot$, and the angle $SEM = \omega$ the inclination of the ecliptic. Now if the angle $KSP = G$ represents the inclination of two planes passing through the line joining the centers of the Sun and Earth, and the poles of the Earth and ecliptic respectively, then in the triangle ESM, right angled at M, we shall have :

$$\cos ES = \cot SEM \cot ESM,$$

or $$\cos \odot = \cot \omega \tan G,$$

whence $$\tan G = \tan \omega \cos \odot ."[2]$$

"Similarly, if H be the inclination of two planes passing through the line joining the centers of the Sun and Earth and the poles of the Sun and ecliptic respectively, we should obtain by a corresponding figure :

$$\tan H = \tan I \cos(\odot - N),$$

where I is the inclination of the Sun's equator to the ecliptic, and N the longitude of the ascending node." (De La Rue, Stewart, and Loewy, *Phil. Trans.*, **159**, 11, 1869.)

[1] More exactly, $\tan \rho = \frac{r}{R}\tan(R'')$, and $\frac{r}{R} = \frac{\sin \rho' \cos \rho + \cos \rho' \sin \rho}{\cos \rho'}$ $= \frac{\sin(\rho + \rho')}{\cos \rho'}$. But $\cos \rho'$ is only a trifle less than unity.

[2] Fig. 2, Plate XXIV, is a view of the celestial sphere from the outside. The line of sight from the Earth to the Sun follows the direction TES, the position of the Earth being at T on the opposite side of the sphere from S. E is the vernal equinox on the nearer side of the sphere. G, then, according to definition, will be positive in the present instance.

Attention must be paid to the signs of G and H. Cos ω is positive in the first and fourth quadrants, and negative in the second and third. For the epoch 1900 A.D.,

$\cos(\odot - N)$ is positive from $\odot = 344^\circ 22'$ to $\odot = 164^\circ 22'$
" " negative " $\odot = 164^\circ 22'$ to $\odot = 344^\circ 22'$.

Hence from

$\odot = 0^\circ$ to 90°, G is positive, H is positive,
90° to $164^\circ 22'$, G is negative, H is positive.
$164^\circ 22'$ to 270°, G is negative, H is negative,
270° to $344^\circ 22'$, G is positive, H is negative,
$344^\circ 22'$ to 360°, G is positive, H is positive.

The heliographic coördinates of the center are derived in the following way: In Fig. 3, Plate XXIV, P is the pole of the Sun, K the pole of the ecliptic (exaggerating the angle between them for the sake of clearness). C is the position of the Earth upon the celestial sphere, ΥC being the Earth's celestial longitude, or $180^\circ + \odot$. N is the position of the ascending node of the Sun's equator on the ecliptic. In the final equations, the letter N also stands as a symbol for the arc ΥN.

NC = a part of the ecliptic $= (\odot - N) - 180^\circ$.
$L = NM$ = nodal heliographic longitude of the Earth.
[1] $D = MC$ = heliographic latitude of the Earth.
$I = MNC$ = inclination of the solar equator to the ecliptic.

From the triangle MCN, right-angled at M, we have

$$\tan L = \cos I \tan(\odot - N)$$
$$\sin D = \sin I \sin(\odot - N).$$

The signs of the functions of $(\odot - N)$ for the epoch 1900 A.D. are:

$\tan(\odot - N)$ positive from $\odot = 74^\circ 22'$ to $\odot = 164^\circ 22'$
" negative from $\odot = 164^\circ 22'$ to $\odot = 254^\circ 22'$
" positive from $\odot = 354^\circ 22'$ to $\odot = 344^\circ 22'$
" negative from $\odot = 344^\circ 22'$ to $\odot = 74^\circ 22'$
$\sin(\odot - N)$ positive from $\odot = 74^\circ 22'$ to $\odot = 254^\circ 22'$
" negative from $\odot = 254^\circ 22'$ to $\odot = 74^\circ 22'$.

[1] In the present case D is negative, and the expression involving $(\odot - N)$ must be interpreted accordingly.

For the transformation of celestial into nodal heliographic coordinates, we have these equations:

$$\tan a = \sin \lambda \cot \beta, \tag{11}$$

$$\tan L' = \frac{\sin (I + a)}{\sin a} \tan \lambda, \tag{12}$$

$$\sin D' = \frac{\cos (I + a)}{\cos a} \sin \beta. \tag{13}$$

where a is an auxiliary arc, λ stands for celestial longitude, and β for celestial latitude (heliocentric), and L' and D' are the corresponding quantities in the solar arcs. These formulæ are needed for comparing the positions of Sun-spots with those of planets or comets in testing the possible connection, or at least coincidence of their conjunctions, etc. From these formulæ we may also deduce the nodal heliographic positions of the celestial pole, but more simply as follows. Since the angle between the solar and terrestrial rotation-axes is the same as that between their equators, the projection of the Sun's north pole on the celestial sphere is $26° \ 17'$[1] from the north celestial pole, or in declination $63° \ 43'$. Its right ascension is $90°$ behind the point Q, the ascending node of the Sun's equator on that of the Earth, or $74° \ 05'$ behind the vernal equinox, that is, the right ascension of the Sun's north pole is $285° \ 55' = 19^h \ 3^m \ 40^s$. In like manner, the nodal heliographic coördinates of the Earth's north pole are:

$$D_N = 90° - 26° \ 17' = 63° \ 43'$$
$$^{2} L_N = 90° - 59° \ 54' = 30° \ 6' \qquad \text{(Epoch 1900).}$$

In what precedes, we have considered what is virtually a projection of the celestial sphere inwards upon the Sun-sphere, which in turn is viewed from without, and must not be confounded with a star-map which is supposed to be projected outwards upon the inner concave surface of the celestial sphere, or

[1] In Plate XXIII, the angle between the solar and the terrestrial equators is $Q = 180 - ♈ \, Q N$, and $\frac{1}{2} \cot ♈ \, Q N = \dfrac{\sin \frac{1}{2} (Q N + ♈ Q)}{\sin \frac{1}{2} (Q N - ♈ Q)} \times \tan \frac{1}{2} (\omega - I)$.

[2] The arc $59° \ 54'$ is the amount by which the intersection of the solar and terrestrial equators precedes the Sun's node.

on some tangent plane, cone, or cylinder, and which is viewed from the inside. The former is an artificial or composite conception. If the point of view is in the prolongation of the Sun's axis of rotation, and at an infinite distance, we get the appearance shown in Plate XXIII. As seen from the Earth, however, the appearance of the Sun and its chief circles is as represented in the twelve diagrams (one for each month) in Ball's *Story of the Sun* (Fig. 39, p. 154). Both kinds of figures are needed to complete the conception of the relations between the diverse planes and nodes. Plate XXIII is of especial use as a test of the student's comprehension of the subject. From the scarcity of accurate representations of the solar zones in their varying presentation, one might infer that these relations are not often studied even by professional astronomers. The subject, however, is not inherently difficult, and with the help of the diagrams mentioned, and a little exercise of the geometrical imagination, all of the statements made here should be easily verified.

A projection-drawing of the Sun cannot be viewed from behind, like a photographic transparency, without subjection to some modifying process. In order to see the parts in their true relation, the drawing may be inverted on an illuminated glass table, and traced through on the back side of the paper. If a concave eyepiece lens (Galilean telescope) has been used in getting the projection, the drawing (held in its original position) should be rotated about its east and west diameter, when the reverse will be correctly oriented; but if a convex eye-lens has been employed in projection, the drawing, previously held with its north point uppermost, must be rotated about a vertical diameter to give the direct view as seen from the back.

We come now to the final object of our labor — the reproduction of important heliographic circles and points upon the face of a Sun-picture, and the quantitative determination of their positions. Every Sun-picture should have its east and west line carefully determined, and the orientation correctly labeled. The eyepiece used in projection, and the date and time of the

picture, should also be added. If the whole Sun has been drawn, the diameter of the circular margin, in conjunction with the angular diameter of the Sun given in the ephemeris, will fix the scale; but if only a part of the solar surface has been depicted, a series of transits of the Sun's limb, or of a sharp spot, between spaced lines on the drawing should be chronographically timed, giving the means of finding the scale.

In plotting the fundamental data upon a Sun-picture, the projection of the pole of the ecliptic (angle G) is first laid off from the north point on the limiting circle, and a similar construction from the east point will give a marginal point which, joined to the center by a straight line, shows the direction of the Sun's annual apparent motion.

Next, laying off an arc of $7\frac{1}{4}$ degrees on either side of the ecliptic pole, its chord will be the path in which the Sun's pole travels, and the angle H, laid off by the protractor on this chord, fixes the position of the Sun's pole and axis. The major axis of the solar equatorial ellipse may be drawn through the center at right angles to the polar axis. Drawing a chord at right angles to the polar axis through the projection of the Sun's pole, this chord is also the minor axis of the equatorial ellipse.[1] With these data the ellipse is readily constructed. The rear half is preferably dotted. The nodal heliographic longitude of the center being that of the Earth (L), the heliographic longitude of the solar prime meridian from the center of the disk is L–l', and this angle being computed in the manner to be described in the concluding article may be laid off on the margin from the projection of the Sun's polar axis. The marginal point thus obtained is to be projected on the equatorial ellipse by a line parallel to the polar axis, giving the projection of the origin of heliographic coördinates. The Sun's node will always be at the intersection of the equatorial ellipse and the ecliptic trace.

[1] The reasons for these procedures will be evident to all who are familiar with descriptive geometry. Mr. R. A. Proctor has explained the method of construction as applied to a special case of planetary presentation in *Old and New Astronomy* (p. 456), and has given the mathematical principles involved in *M. N.*, **38**, 320. 1878.

These lines and points will ordinarily be sufficient to insure a correct conception of the solar presentation.[1]

All solar arcs will ordinarily be reckoned heliocentrically but for precision this, or an equivalent term, must be included in their nomenclature. In analogy with the term geographic longitude, it is customary to use the expression *heliographic longitude* to denote longitude reckoned heliocentrically along the Sun's equator from an assumed solar prime meridian. For example, we have *heliographic longitude from Carrington's prime meridian* which coincided with the Sun's node at the epoch, Greenwich mean midnight between December 31, 1853 and January 1, 1854, and which is arbitrarily assumed to have a true rotation period of 25.38 days, this being approximately the sidereal rotation period of an average Sun-spot. Again, we have *heliographic longitude from Bigelow's prime meridian* which was central on June 12.22, 1887, and is assumed to have a synodic rotation period of 26.67928 days, agreeing with a supposed periodicity of terrestrial magnetism attributed to solar influence, and possibly representing

[1]Comparison with a diagram similar to Plate XXIII, or with a solar globe, orienting the figure, or the globe, according to the place of the Earth in its orbit, will be found useful as a check on the accuracy of these constructions. In making such a diagram or globe, the following points are the principal ones to be considered. The solar equator being drawn, the poles of the various systems of coordinates follow, according to the precept already given. (Ante p. 408.)

On Plate XXIII, QMN being an arc of the solar equator, and ΥCN an arc of the great circle in which the ecliptic plane intersects the surface of the Sun-sphere, we have:

Point Υ = the ascending node of the ecliptic, or to be precise, this point is the intersection at the Sun's surface of the plane of the Earth's orbit with a plane through the Sun's center parallel to the Earth's equator. The direction of Υ from the Sun's center is also that of the Earth at the autumnal equinox. The angle $N \Upsilon Q = \omega = 23^\circ 27'$.

Point Q = the ascending node of the Sun's equator on a plane through the Sun's center parallel to the Earth's equator. The angle $Q = 180^\circ - \Upsilon QN$ = inclination of Sun's equator to Earth's equator = $26^\circ 17'$ for the epoch 1900 A.D.

Point N = the ascending node of the Sun's equator on the ecliptic. The angle $\Upsilon NQ = I = 7^\circ 15'$.

The arc ΥQ = the right ascension of point $Q = 15^\circ 55' = 1^h 3^m 40^s$. The arc QMN = the nodal heliographic longitude of point Q, or reckoned in the usual direction, $L_0 = 300^\circ 6'$.

The arc ΥN = the celestial longitude of the Sun's node, for which has been adopted the symbol $N = 74^\circ 22'$, for 1900 A.D.

the rotation of a fairly coherent and unsymmetrically magnetic solar nucleus in a true rotation period of about 24.86 days.[1]

Nodal heliographic longitude, or heliographic longitude *from the Sun's node*, is longitude reckoned heliocentrically along the Sun's equator from the Sun's ascending node on the ecliptic. For this kind of longitude the symbols L, or l, have been used in this article.

[1] FRANK H. BIGELOW, *Monthly Weather Review*, issued by the United States Weather Bureau, for March 1895, p. 91.

ON THE PRESENCE OF CARBON IN THE CHROMOSPHERE.

By George E. Hale.

In an article on the Yerkes Observatory, published in 1892,[1] I called attention to the advantages which the forty-inch telescope seemed to offer for solar investigations, and outlined a general plan of work in this field. The results of the photographic observations of the ultra-violet spectrum of the chromosphere, then in progress at the Kenwood Observatory, convinced me that certain advances in our knowledge of the spectrum of the Sun's limb might reasonably be expected to follow from work with a large solar image.

In September of the present year, when it became possible for the first time to undertake spectroscopic observations with the large telescope, I attached to the instrument the solar spectroscope which formerly belonged to the Kenwood Observatory, where it had been used with the 12-inch refractor. The collimator and observing telescope of this spectroscope are each of $3\frac{1}{4}$ inches aperture and $42\frac{1}{2}$ inches focal length. As the ratio of aperture to focal length in the forty-inch telescope is $\frac{1}{19}$, the effective aperture of the solar spectroscope is only about 2.2 inches. The grating has 14,438 lines to the inch on a ruled surface $1\frac{15}{16}$ by $3\frac{3}{16}$ inches. The greater part of the observations were made in the second order spectrum, though the third was sometimes employed.

On September 14, when the first observations of the chromospheric spectrum were made with these instruments, the color curve of the forty-inch objective had not been determined. In spite of the consequent uncertainty regarding the focus for dfffferent parts of the spectrum, many bright lines were seen at each point of the limb examined, though there were no evidences of eruptive activity. On September 16 similar results were obtained. On September 18 some twenty-five bright

[1] *Astronomy and Astrophysics*, 11. 790, 1892.

lines were seen in the region λ 5198–5363. The wave-lengths were determined by comparison with Rowland's map, and it was found that several of Young's low-frequency lines had been observed, while two or three of the lines were apparently new. In this case, as in the others, there was no evidence of an eruption. On September 25 the color curve was roughly determined by means of observations of the Sun's limb with a radial slit, and the driving-clock was adjusted for solar rate. Over thirty bright lines were seen between C and D, and one or two new lines were found. On September 29 the seeing was so good that the form of the chromosphere could be well seen with a power of about 700. With a narrow slit an extraordinary number of bright lines were visible. In the region just above *b* the lines were closely grouped together, and seemed to form a fluting. Suspecting the presence of the green carbon band, I carefully determined the position of the head of the fluting in the solar spectrum. The wave-length thus obtained corresponded as accurately as the precision of the observation allowed with the known wave-length of the red edge of the carbon fluting. The wave-lengths of the individual dark lines of the fluting which occur in the solar spectrum are given in Rowland's Table of Solar Spectrum Wave-lengths. Using a narrow slit, placed nearly tangential to the Sun's limb, which slightly overlapped it, the dark lines of the disk were seen to become bright where the slit crossed the chromosphere. In another observation the procedure was slightly different. The slit was set on the Sun's disk near the limb, where the dark lines ascribed by Rowland to carbon could be seen. Fixing his attention on one of these lines, the observer, by pressing against the tube, moved the telescope sufficiently to bring the slit into the chromosphere. Several lines examined in this way were found to be reversed in the chromosphere. The head of the fluting was also reversed in the same way. M. Deslandres, who was visiting the Observatory at the time, kindly examined the chromospheric spectrum, and had no difficulty in seeing the new lines. They have since been observed on several occasions by Professor Runge, Professor Keeler, and others. Although I intend to make further com-

parisons of carbon and chromosphere lines, I consider the observations already made sufficient to demonstrate the presence of carbon in the chromosphere.

As the lines were on each occasion seen at every point of the limb examined, I am inclined to think that they form a part of the normal spectrum of the undisturbed chromosphere, and that they will be visible with the forty-inch telescope whenever the atmospheric conditions are good. The layer of carbon vapor is thin, and it is consequently necessary to have a large image and good seeing in order to render the lines visible.

After the observations had been made, I found that Professor Young had recorded in his partial revision of the chromospheric spectrum a line at λ 5165.2, of frequency 3, intensity 5, element C ?, with the following remarks: "High-level line, unmistakable on the photographs; dark line extremely faint, if visible at all; agrees exactly with C marked upon Rowland's map." The photographs referred to were taken on June 20, 1893, by Professor Reed, "during an energetic outburst of chromospheric activity." Although the wave-length given by Rowland for the head of the fluting differs about a quarter of a tenth-meter from the value given by Professor Young, there can be little doubt that the head of the carbon band was really photographed. As the distance between b_1 and b_4 on the negatives is only about a tenth of an inch, such an error might easily have been made in estimating the position of a line. Through the kindness of Professor Young, I have had an opportunity to examine two of these plates. The bright line just referred to is well shown, but, as one might expect from the conditions in which the photographs were made, there appears to be no trace of the rest of the fluting on any of the negatives.

After consulting Professor Young, who declares himself in full sympathy with the plan, I have decided to undertake a revision of the chromospheric spectrum with the forty-inch telescope. The excellent seeing enjoyed here during the summer months should greatly facilitate the work.

YERKES OBSERVATORY,
October 1897.

Minor Contributions and Notes.

PROCEEDINGS OF THE CONFERENCES HELD AT THE YERKES OBSERVATORY, OCTOBER 18–21, 1897.

The following synopses of the papers read at the astronomical and astrophysical conferences held at the Yerkes Observatory in connection with the dedication, have been prepared by the authors. In some cases only the title is given, on account of the author's desire to publish the complete paper in the Astrophysical Journal or elsewhere. The order of the papers is that in which they were read at the conferences.

ON THE MODE OF PRINTING MAPS OF SPECTRA AND TABLES OF WAVE-LENGTHS.

My opinion with regard to the mode of printing maps of spectra and tables of wave-lengths agrees very nearly with that expressed by Professor Keeler in the August number of this Journal. It does not seem to me to be a matter of very great importance what decision is arrived at, but in whatever way the question is settled, all spectroscopists should conform to a uniform practice, even if it involves a little personal inconvenience at first. In making the few remarks which have occurred to me in connection with this matter I will take up the two questions separately.

1. *Mode of printing maps.* – What has determined the mode of printing maps? No doubt the particular construction of the spectroscopes employed by different observers. Fraunhofer must have had his spectroscope constructed so that he saw the red to the left, while Kirchhoff placed his prisms so that he saw the colors of the spectrum in the reverse direction. Many students first become acquainted with the appearance of the spectrum by means of the plates copied from Bunsen and Kirchhoff's first paper, in which the red is placed on the left; and hence they cannot picture to themselves the spectrum in any other way. Small spectroscopes are also, I believe, almost invariably made now so as to place the red on the left. The only reason for this that I can see, is that the observer while looking at the spectroscope

ought to be able to handle the slit and flame or spark in front of the slit, and it is generally more convenient for him to use his right hand for the purpose. With single-prism spectroscopes this would render it necessary to construct them so that the red is on the left. But that is not an important matter, for physicists ought to be able to open or close the slit with the left hand. It would be well, however, if the practice of placing the red is adhered to, to get instrument makers to construct their spectroscopes accordingly, and architects to build their lecture rooms with the lantern on the right and the screen on the left. There may be some natural tendency in human beings which would favor one direction more than another. The way to find this out would be to place a small direct vision spectroscope in the hands of scientifically uneducated persons and to observe which way they hold it. My own experience would lead me to think that they would place the slit horizontal, so that the red would be either top or bottom; and there may even be something to be argued in favor of that practice. I only bring out these points to show that one might discuss the question indefinitely, and if one could start fresh from the beginning I do not know whether the balance of unimportant considerations would not turn in favor of having the red on the left. But Rowland's map is constructed with the red on the right, and this fact outweighs, in my opinion, all other considerations. In the majority of spectroscopic investigations of the present day Rowland's map has to be used, and it would be unbearable always to have to invert the direction. I should be sorry, therefore, if the present practice of the ASTROPHYSICAL JOURNAL were altered. Any one, of course, is at liberty to print a scale with inverted numbers at the bottom of a map, so that by turning the page around the smaller wave-lengths appear on the right. The question of series of lines I will discuss presently.

2. *Mode of printing tables.* Here also most arguments which have been used in favor of one practice rather than another do not seem to me of very great weight. Wave-frequencies are quantities as important as wave-numbers, and if the latter succeed each other according to increasing figures, the former do so in the opposite way. But here the question of series has to be taken into consideration. It certainly seems more natural to print a series of lines which gradually become fainter so that the strongest should appear at the top. I would for this reason favor the reversal of the practice recommended by the Editorial Board. It has been argued that in printing maps the first and strong-

est lines of the series, and hence the red end, should be on the left, but I do not see that this is a matter of paramount importance. To my mind a series looks as well with the tail on the left as the other way around; with the present practice of the JOURNAL no doubt the characteristic numbers of the lines in a series would increase from right to left, but I do not know that this is unnatural. A great many nations write from right to left and if one were to count a row of soldiers it would be as easy to begin at one end as at the other. Those who are accustomed to consider a positive rotation as one opposite to that of the hands of a watch would, I believe, not find it unnatural when the first impulse is overcome to look at a series as beginning on the right hand side and tailing off on the left. Counting things from right to left seems to me to belong to a more advanced civilization than our present practice, which is the consequence of the apparent rotation of the Sun around the Earth. As soon as we realize that it is the Earth that rotates, the left handed way of counting things becomes the more natural one. Giving all due weight to the fact that Kayser and Runge's practice is to have the head of a series on the left, I believe that Rowland's map must settle the question as to the position of the red end, while in the matter of printing tables the increasing importance of Kayser and Runge's series renders it advisable to reconsider and probably to reverse the present mode followed by the JOURNAL.

While I am writing on these subjects I should like to mention two matters which might deserve the attention of the Board of Editors. One is the position of the decimal point in tables of wave-lengths or wave-numbers. In tables of the former, the practice of giving four figures in front of the decimal point is almost universally adopted, and should, in my opinion, be adhered to. But no general system is followed for wave-frequencies, and there seems to me to be a great advantage, chiefly as a help to the memory, if the number given should always be the number of wave-lengths in the centimeter. This would give five figures, the wave-number for green light, *e. g.*, being 20000.

The other question refers to the notation for the intensity of light. I do not know whether it will be possible at the present stage of science to come to a definite agreement, owing to the difficulty of using the the same system for two such very different things as the solar spectrum and a spark spectrum. As a first step, however, I should like to urge that the higher intensities, whatever the scale, should always be denoted by the higher numbers. This is the practice adopted by the

majority of physicists, and it is a matter of some inconvenience to compare together the results of two researches, in one of which the number one denotes the greatest intensity, while in the other the same number stands for the weakest line. A scale reaching from one to ten, using decimal points if necessary, might perhaps commend itself, but personally I am willing to adopt any practice which may be decided upon.

ARTHUR SCHUSTER.

SPECTROSCOPIC NOTES.

By Sir William and Lady Huggins. (Published in the ASTROPHYSICAL JOURNAL, November 1897.)

THE VARIABLE STAR WORK OF THE HARVARD OBSERVATORY.

Professor Edward C. Pickering described the studies of variable stars in progress at the Harvard College Observatory. Variables of long period have been observed for many years throughout their variations, at minimum as well as at maximum. A sequence of comparison stars is selected for each, the variable is compared by Argelander's method, and all the results reduced to a uniform scale, that of the meridian photometer. Short period variables are measured with the meridian photometer and with a polarizing photometer attached to the large telescope. Smooth light curves are thus obtained. The variable stars, S S Cygni and U Geminorum, form a peculiar class. The first of these stars was observed on about two hundred nights. Photometric observations of it were made extending over the whole of one night during its rapid increase. Many thousand observations have been made of the Algol stars, especially of U Cephei and W Delphini, the most accurate timekeepers we have outside of the solar system.

STUDIES OF THE ELECTRIC ARC.

Professor Crew described a method of studying the electric arc which had been devised by himself and Mr. O. H. Basquin.

By working the arc in a hood filled with a gas which has no chemical action upon the electrodes, they avoid any luminosity which might be called a "chemical effect."

By the use of a rapidly rotating occulting screen, they examine the arc immediately after the current has been cut off, and thus avoid any luminosity which might be called an "electrical effect."

By the use of an alternating current, interrupted at the moment when the current-curve crosses the axis of X, they avoid "self-induction effects." In this manner the "purely thermal effects" are isolated.

It is found, however, that when the current is shut off different parts of the arc persist for different lengths of time. A spectroscopic examination of the different parts of the arc, and of arcs in different gases, is now in progress.

RESEARCH WORK AT THE WASHBURN OBSERVATORY. STELLAR PARALLAX, THE LUNAR ATMOSPHERE, THE OCULAR HELIOMETER.

The following summary of a paper presented to the astronomical conferences at the Yerkes Observatory is limited to two of the lines of research now in progress at the Washburn Observatory, the one by Mr. A. S. Flint, being an extensive series of determinations of stellar parallax made with the Repsold meridian circle used as a transit instrument in accordance with the principles outlined by Kapteyn (*Leyden Annalen* Bd. VII), the other, of very much less extent, being an investigation by the Director of the Observatory of the limits of density of an assumed lunar atmosphere whose existence is affirmed by many selenographers. In connection with the latter subject there was exhibited at the Williams Bay conferences a Steinheil ocular heliometer obtained for use in this investigation, but which in its present form has proved unsatisfactory because certain conditions which theory indicates as essential in such an instrument were not observed in its construction.

A brief notice of this type of micrometer has been given by Gill (*Encyclopædia Britannica*, article "Micrometer,") who condemns it as a failure; and a much more complete account by von Konkoly (*Centralzeitung für Optik und Mechanik*, July 1885), who assigns it the first rank among all known forms of double image micrometer. The writer of the present lines cannot agree entirely with either of these critics, but regards the instrument as possessing good points which at present are rendered in great part nugatory by theoretical defects of construction whose exposition lies beyond the scope of the present article.

The determination of relative parallaxes through observed differences of right ascension contains nothing novel in principle, but the method does not appear to have been applied systematically and successfully save by Kapteyn and in the work here to be outlined. The observing programme contained about a hundred stars chosen for the most part with reference to large proper motion and intended to com-

prise every star within 120° of the north pole whose proper motion exceeds one second of arc of a great circle. A certain number of these stars were, however, dropped from the list as being too faint for the very modest aperture, 122^{mm}, of the instrument, and their places, together with other lacunæ, were filled with other stars, usually interesting binaries or bright stars whose parallaxes elsewhere determined may serve as a control upon the general accuracy attained.

A normal observation consists in recording chronographically the times of transit over 25 threads of the star in question and two comparison stars so chosen that the star under investigation shall as nearly as may be bisect the arc joining them. It was in most cases feasible to select comparison stars which had not previously been employed for parallax determinations, but in some few cases, *e. g.*, Sirius and 61 Cygni, this was not done and could not be done without an undue sacrifice of other conditions. All of the stars observed were reduced to an approximate equality of brightness by the interposition of wire gauze screens immediately in front of the objective. An elevated track attached to the walls of the observing room supported these screens and permitted their convenient adjustment without allowing any part of the apparatus to come into contact with the telescope or its supports.

The parallax observations were commenced in October 1893, and terminated in August 1896, and the very laborious reductions are now sufficiently advanced to furnish the following results, each of which has been derived from a least squares solution involving in addition to the parallax a correction to the assumed relative star places and proper motions.

Star	Mag.	R. A.	Dec.	P. M.	Observed Parallax	Other Determinations
		h m				
Gr. 34	8.1	0 12	43 25	3.8	+0.44 ± 0.03	+0.29 Auwers
η Cassiop.....	3.8	0 42	57 15	2.1	−0.02 ± 0.04	+0.17 Schur
Ll. 7443	8.5	3 56	35 1	2.2	+0.18 ± 0.06	
o^2 Eridani ...	4.7	4 10	−7 49	4.0	+0.31 ± 0.04	+0.17 Gill
α Tauri......	1.0	4 29	16 18	0.2	−0.07 ± 0.06	+0.10 Elkin
W. B. V. 502..	8.7	5 26	−3 41	2.2	+0.24 ± 0.04	
Sirius	1.4	6 40	−16 34	1.3	+0.31 ± 0.03	+0.38 Gill & Elkin
Ll. 30694.. ..	7.0	16 47	0 11	1.0	+0.03 ± 0.04	
Ll. 31055.. .	7.5	17 0	−4 53	1.5	+0.10 ± 0.03	
Σ 2398 *pr*....	8.2	18 41	59 28	3.1	+0.32 ± 0.05	+0.35 Lamp
61 Cygni *pr*		21 2	38 13	5.2	+0.21 ± 0.03	+0.44 Mean of heliometer determ'nat'ns
B. D. 26 4721.	8.1	23 53	26 40	0.1	+0.26 ± 0.04	

According to Neison every selenographer of consequence has recognized traces of a lunar atmosphere which could not be questioned were it not for the authority of Bessel, whose mathematical analysis of the conditions at the lunar surface has seemed to preclude the possibility of any considerable atmosphere. Neison, justly impugning the validity of this analysis, has contended vigorously for the existence of an atmosphere, not indeed comparable in density with that of the Earth, but sufficient to modify profoundly the physical conditions of the lunar surface, and some recent observers have sought to show the existence of a sensible refraction in the light of an object about to be occulted at the Moon's limb.

It is generally conceded that such a refraction furnishes the most delicate test of the presence of an atmosphere, and although the relation between the physical characteristics of the supposed atmosphere (pressure, temperature, refractive index, law of diminishing temperature with increasing elevation) and the amount of the horizontal refraction is not an altogether simple one, no plausible relation can be assumed among these quantities which will reconcile the absence of refraction with the presence of any considerable atmosphere. Employing for the horizontal refraction and the law of diminishing temperatures the expressions of Laplace (*Méc. Cél.* Liv. X), and assuming the lunar atmosphere at standard temperature and pressure to have the same refractive index as air, I find as an approximate expression for the relation between the horizontal refraction, H, and the density, ρ, of the lunar atmosphere in terms of the Earth's atmosphere at sea level assumed as unity.

$$H = 484'' \rho \left(1 - \frac{\tau}{546}\right)$$

where τ represents the temperature at the Moon's surface in degrees C.

It has been customary to assume upon the authority of the Greenwich occultations that H may be as great as 1″ or 2″, but this and all similar determinations appear fatally defective in that the result depends upon an assumed value of the Moon's semidiameter, and I have sought to obtain a value of H free from this assumption by comparing with the filar micrometer of the 40^{cm} Clark equatorial the relative position of two stars as the Moon approaches them; continuing the observations up to the moment of occultation of one of the stars. The distance from the Moon's limb at which the apparent position of a star may be assumed unaffected by the lunar atmosphere depends

upon the extent and density of the latter, and I have provisionally assumed as a result of the analysis leading to the relation between H and ρ above given that if the horizontal refraction does not exceed 1″ the effect of refraction will not in general be sensible until within two minutes of the occultation of the star.

The observations thus outlined are difficult of execution and stars suitably placed cannot be found at all times, but practice and patience have in some measure overcome these difficulties and have furnished the following results for the amount, $2H$, by which a star at occultation is thrust away from the Moon's limb. Each result is entirely independent of the others and is derived from an immersion at the Moon's dark limb.

Date	2 H	Date	2 H
1897, May 8,	− 0 .3	1897, July 5,	− 0 .0
8,	+ 0 .0	6,	+ 0 .7
9,	+ 0 .3	Oct. 3,	− 0 .6
9,	+ 0 .2	3,	+ 0 .3
9,	− 0 .4	3,	0 .8
July 5,	+ 0 .3	3,	− 0 .4

The mean of these results furnishes $H = -0''.03$, which differs from zero by less than its own probable error and which appears to me absolutely irreconcilable with any such value as $H = 1''$, although the number of results thus far obtained is not sufficient to furnish a definitive value. The temperature at the dark limb of the Moon is almost certainly below 0° C. and if we adopt this value for τ and take as the maximum permissible value of H, one-tenth of a second of arc, we shall have $\rho = \frac{1}{4840}$, *i. e.*, the maximum density of the permanent lunar atmosphere can not much exceed one-five-thousandth part of the density of the terrestrial atmosphere. If, as has been supposed by some astronomers, ice exists in considerable quantities at the surface of the Moon, the change of temperature which accompanies the transition from night to day may produce a local and temporary atmosphere of aqueous vapor in certain parts of the Moon's surface and it is to be noted that the foregoing observations furnish no information with regard to the presence or absence of such an atmosphere, since they were all made on the night side of the Moon.

George C. Comstock

THE AIM OF THE YERKES OBSERVATORY.

By George E. Hale. (Published in the ASTROPHYSICAL JOURNAL, November 1897.)

SPECTRA OF STARS OF SECCHI'S THIRD TYPE.

Professor Keeler showed on the screen a series of photographs of stellar spectra, mostly belonging to Secchi's third type. The slides were positive enlargements (ten diameters) of negatives made with the thirteen-inch refractor and star spectroscope of the Allegheny Observatory. Some of the spectra had been widened, by means of a movable camera, during the process of enlargement. They showed a great amount of detail which can be seen only with great difficulty by direct observation with the spectroscope. Five slides were required to show the spectrum of α Orionis from D to F.

In photographing the less refrangible regions of stellar spectra the chief difficulties arise from the unequal sensitiveness of orthochromatic plates to rays of different wave-lengths. The inequalities of density thus produced can be partially corrected in making the enlargements, by suitably graduating the exposure, but only a comparatively short range of spectrum can be well represented, and a number of different negatives are required to exhibit satisfactorily the whole region which the plate is capable of yielding. This region, however, often contains the most interesting and characteristic features of the spectrum.

The series of slides included the spectra of α Bootis, α Aurigae, α Tauri, α Orionis, α Scorpii, β Pegasi, and α Herculis, in which may be observed a transition from the second to the third type. In stars like α Orionis the lines are essentially those of the solar spectrum, but the relative intensities are not the same, and the general aspect of the spectrum is quite different from that of the spectrum of the Sun. The dark bands characteristic of third-type stars are well shown, though they are not resolved into lines. The separate lines are doubtless far beyond the resolving power of the instrument. These bands are not always terminated by strong metallic lines, and the appearance noted by early observers was probably due to insufficient optical power. The strong lines are mostly those of iron — apparently the low temperature lines. Their relatively greater strength in the star spectrum gives to some well-known solar groups (notably the *b* group) quite an unfamiliar aspect.

In α Herculis only a comparatively few of the strong metallic lines remain, while the bands are deep, and beautifully distinct. It is impossible to avoid the conclusion that the edges of the zones bordering on the dark bands are bright — much brighter, that is, than the average continuous spectrum, — and that they are due to a real predominance of emission at the regions of the spectrum in which they occur. They are not merely the effect of absorption in adjoining regions. In the case of stars like α Orionis, of a less pure type, such a conclusion could not be safely drawn; yet the superior brightness of the spectrum at these places is obvious, and it can be traced even in second-type stars. May there not after all be bright regions in the solar spectrum, such as Draper supposed he had found in the places of the bright oxygen lines? And what is the relation between the dark bands in third-type stars and the bright zones which border on them?

JAMES E. KEELER.

THE STELLAR SPECTROGRAPHIC WORK OF THE EMERSON McMILLIN OBSERVATORY.

In giving an account of my experience in the determination of motions in the line of sight, I would call attention to the great difficulty attending such work when the telescope employed is not corrected for the photographic portion of the spectrum. Numerous attempts were made in the fall of 1896, but the results were unsatisfactory; and the special photographic corrector described in Vol. VI, No. 2, of this JOURNAL was ordered. This lens was not in place until June 1897, and it was not until July that the adjustments were completed so that systematic work could be started. A reflecting slit was employed on account of its superior advantages in following. A 90° total reflecting prism was used to reflect the light from the comparison tube (hydrogen) on the slit. To adjust the comparison tube, the prisms were removed and a ground glass cap placed over the collimator objective; the entire apparatus was then moved until with a wide slit the collimator was shown to be full of light. The slit was then closed to the desired width, about the $\frac{1}{1000}$ part of an inch. In this way a number of photographs were taken which, though for the most part fairly satisfactory, showed some large discordancies. A careful investigation of the instrument was then undertaken and the trouble finally located in the jaws of the slit, as it was found that as the slit was closed a shadow would creep across the collimator objec-

MOTION OF STARS IN THE LINE OF SIGHT.

Plate number	Date 1897	Star	Observed velocity: Red end right	Observed velocity: Red end left	Reduction to the Sun	Velocity reduced to Sun: Red end right	Velocity reduced to Sun: Red end left	Velocity reduced to Sun: Mean	
384	Sept. 3......	γ Cygni	+ 2^{km}.8	— 2^{km}.9	— 5^{km}.2	— 2^{km}.4	— 8^{km}.1	— 5^{km}.2	
387	" 4......		+ 4 .3	± 0 .0	— 5 .4	— 1 .1	— 5 .4	— 3 .2	Mean — 4.1.
392	" 7......		+ 2 .9	— 2 .9	— 6 .0	— 3 .1	— 8 .9	— 6 .0	Potsdam mean — 6.4
397	" 14......		+ 7 .2	+ 1 .4	— 8 .0	— 0 .8	— 6 .6	— 3 .7	
398	" 14......		+ 8 .6	+ 2 .9	— 8 .0	+ 0 .6	— 5 .1	— 2 .3	
408	" 18......	α Orionis	— 1 .4	— 8 .7	+28 .3	+26 .9	+19 .6	+23 .2	Mean +21.4
414	" 22......		7 .2	—10 .0	+28 .3	+21 .1	+18 .3	+19 .7	Potsdam mean +17.2
388	" 4......	ϵ Pegasi	+15 .8	+10 .1	— 6 .1	+ 9 .7	+ 4 .0	+ 6 .8	Mean +9.9
394	" 10......		+20 .1	+14 .4	— 8 .9	+11 .2	+ 5 .5	+ 8 .3	Potsdam mean + 8.0
396	" 12......		+24 .4	+24 .4	— 9 .7	+14 .7	+14 .7	+14 .7	
391	" 4......	α Cassiop.	—12 .9	—17 .2	+12 .2	— 0 .7	— 5 .0	— 2 .8	Mean 0.6
400	" 14......		8 .6	—15 .8	+13 .8	+ 5 .2	— 2 .0	+ 1 .6	Potsdam mean —15.2
436	Nov. 17......	α Arietis	± 0 .0	4 .3	—10 .4	—10 .4	14 .7	—12 .6	Mean —14.0
440	" 20......		— 0 .0	7 .2	11 .7	—11 .7	18 .9	—15 .3	Potsdam mean — 14.7

MOTION OF VENUS IN THE LINE OF SIGHT.

Plate number	Date 1897	Observed velocity: Red end right	Observed velocity: Red end left	Observed velocity: Mean	Comp. velocity
403	Sept. 14.......	+11.5	+8.3	+ 9.9	+10.6
409	" 18.......	+12.5	8.6	+10.6	+10.2
417	" 22.......	+16.5	4.7	+10.6	+10.1

tive from one side, upon which no adjustment of the comparison tube produced the slightest effect.

The reflecting slit was then replaced by one of the ordinary form and the hydrogen tube placed directly in the cone of rays about seven inches in front of the slit, being turned out of the way during the exposure on the star. A number of photographs of the sky showed satisfactory agreement between the solar and artificial $H\gamma$, the maximum displacement being only $0^{mm}.002$.

As this trouble was not discovered until late in August but few results can be shown. Observations of γ Cygni, α Orionis, ϵ Pegasi, α Cassiopeiae and Venus showed a constant positive difference from the Potsdam results on the stars and the computed velocities of Venus. It occurred to me that this might be due to a personal equation depending upon the direction of the plates under the microscope. In every case the red end had been placed on the right. The plates were remeasured with the red end on the left and a similar negative difference found, the mean of the two agreeing in almost every case with the Potsdam values. The final results together with a few additional ones are given in the table. It should be stated that two dense 60° prisms were employed and that in the neighborhood of $H\gamma$ 1^{mm} displacement on the plate corresponds to a velocity of $143^{km}.7$ per second. The large discordancy in the case of α Cassiopeiae is as yet unexplained.

H. C. Lord.

ON THE APPLICATION OF DIFFRACTION PHENOMENA TO ASTRONOMICAL AND ASTROPHYSICAL MEASUREMENTS.

By F. L. O. Wadsworth. (To be published in the *Bulletin Astronomique.*)

OXYGEN IN THE SUN.

When I asked Professor Hale to put the subject of "Oxygen in the Sun" on the list for the conferences, I thought that we should have a discussion about it. I learned, however, since then, that there is no more occasion for controversy, the former opponent now holding the same views. Let me therefore merely state how the evidence for the presence of oxygen in the Sun now stands.

Professor Paschen and I discovered three strong lines in the utmost red part of that spectrum of oxygen which Schuster has called the compound line spectrum. It is produced in a vacuum tube by an induction

current, without a Leyden jar and without a spark gap. On measuring these three lines we found that they coincided as nearly as we could make out, with three Fraunhofer lines that we found in the photographs made of this region by McClean and Higgs. The relative intensities were also the same, and this region of the spectrum not having many lines, there remains very little doubt that the coincidences are real. As to the proof of the presence of oxygen in the Sun, it therefore only remained to be shown that these three lines are not produced in the Earth's atmosphere, but that they are true solar lines.

When Paschen and I published this result, Mr. Jewell immediately took up the question. He examined the three Fraunhofer lines and came to the conclusion that they were atmospheric lines due to water vapor. Now this conclusion seemed to us very impossible indeed. We were ready to accept the view that the lines were due to atmospheric oxygen. But that they were due to water vapor would make the coincidences with the lines of the vacuum tube accidental, and three lines coinciding with lines of the same relative intensities in a region that contained so few lines, we could not believe to be a matter of chance. It was for this reason that I asked Professor Hale to let me have a discussion with Mr. Jewell at the conferences. Since his first observations, however, Mr. Jewell has not remained satisfied with the evidence, and he found that he had been misled by the want of a proper absorbent of the second order spectrum, that overlaps the first order spectrum, in which he was observing. The second order spectrum makes the Fraunhofer lines of the first order shine with violet light, and as the absorption of the violet light increases more rapidly with the Sun's zenith distance than the absorption of red light, the first order lines seemed to increase in intensity. After he found the right sort of absorbent to cut off the second order he repeated his observations, and the result is that he now withdraws his first conclusion. He finds that as far as his observations go the intensity of the three lines in question alters in the same way as true solar lines.

One might therefore almost say that the presence of oxygen in the Sun is proved. Further evidence is gained from other lines. Paschen and I have shown that this red triplet is the first member of a principal series. We have found and measured the second member, a triplet of the same build but much narrower,— as narrow as the laws of the principal series requires it to be. This triplet also coincides with Fraunhofer lines, only that the middle line is hidden by an iron line. The

other two lines, however, agree in position satisfactorily with Fraunhofer lines of unknown origin. These Fraunhofer lines are undoubtedly true solar lines, because on negatives made at Johns Hopkins University they show by their shifting the motion of the Sun's limbs in the line of sight. This proof of the presence of oxygen in the Sun I would regard as conclusive, if the lines in this part of the solar spectrum were not so closely set. The evidence of a real coincidence is inversely proportional to the density of the lines, and therefore it is much more convincing in the red part of the spectrum.

The proof would be conclusive if it were shown that the three red lines shift on the limbs of the Sun, and we hope that some one better equipped for this kind of work than we are will take up the subject and will once for all settle the question. C. RUNGE.

EFFECT OF PRESSURE ON WAVE-LENGTH.

Increase of pressure about an electric arc increases the wave-lengths of the spectral lines so produced. This increase is very different for different elements and also for different series of lines of the same element, but the results of the investigation can be expressed fairly well by the simple equation :

$$\Delta \lambda = a \beta \lambda (p - p_0)$$

where $\Delta \lambda$ is the increase of wave-length λ of any given line produced by the increase of pressure $p - p_0$, β a constant for any series of lines and a a constant for any element. That is β for any series of a given element is the same as β for the corresponding series of any other element, while a for any series of a given element is the same as a for any other series of the same element. If we write β for the principal series, β_1 for the first subordinate, and β_2 for the second subordinate, then, approximately, $\beta : \beta_1 : \beta_2 = 1 : 2 : 4$.

By suitably choosing β, a may be replaced in most cases by $\frac{1}{T}$, where T is the absolute temperature of the melting point of the element in question, or by $e\sqrt[3]{V}$, where e is the coefficient of linear expansion of the substance in the solid state and V the atomic volume, or finally, for either half of a Mendelejeff group, by $\sqrt[3]{W}$, where W is the atomic weight. From this last expression it is evident that a, and therefore $\Delta\lambda$, is a periodic function of atomic weight, and consequently the shifts of spectral lines may be compared directly with any other phenomenon which itself is a periodic function of atomic weight.

W. J. HUMPHREYS

THE LATITUDE WORK OF THE FLOWER OBSERVATORY.

I have been asked to give an informal account of the latitude work now in progress at the Flower Observatory, University of Pennsylvania. As to the method — nothing particularly new is involved. It is a continuation with a better instrument and under what are believed to be more favorable conditions of the work upon which I was engaged for a number of years at the Sayre Observatory. Bethlehem.

The instrument is a zenith telescope of four inches aperture and forty-eight inches focal length, by Warner and Swasey.

We have introduced a feature not usually found in connection with this class of instruments, viz., two pairs of long focus collimators, or mires for the purpose of facilitating the adjustment in azimuth and collimation. The latter is somewhat troublesome with instruments of this type ; the telescope not being symmetrically placed with respect to the vertical axis it is not possible to test the adjustment by simple reversal as with the transit instrument. It was a matter of time and patience to place these four mires in position and to adjust them perfectly, but they have proved to be very stable, and by their use the latitude instrument can readily be kept in such perfect adjustment that any star found on the observing list will come to the middle thread within a fraction of a second of its appointed time.

Four groups of stars have been employed for latitude : three groups contain ten pairs, and one group nine. Elsewhere in some cases the number of pairs in a group has in some cases been limited to six or seven ; possibly seven pairs will give results nearly as good as ten. However, when the instrument has been adjusted and six or seven pairs observed it involves but little additional trouble to observe two or three more.

It is an easy matter to state the condition to which an ideal star list should conform, but like other ideals this one cannot be realized in practice. Although much time has been expended upon the present list it falls short of perfection in a number of important particulars. In several cases the choice lay between the admission of long gaps in the series or the filling of these gaps with pairs which were objectionable in one way or another. As a matter of fact, in so far as can be discovered from internal evidence, these less desirable pairs appear to give nearly as good results as those which seemed to be deserving of more confidence.

The distribution in right ascension is as follows:

Group	I	$5^h 28^m$ —	$7^h 9^m$
"	II	12 48	14 52
"	III	17 19 —	19 26
"	IV	21 29	23 28

Observation began October 1, 1896.

Groups IV and I were observed from	Oct.	1	to	Nov. 27,	'96
Group I alone " " "	Dec.	14	"	Jan. 11,	'97
Groups I and II " " "	Jan.	23	"	Mar. 13,	'97
Group II alone " " "	Mch.	16	"	Apr. 20,	'97
Groups II and III " " "	May	7	"	June 2,	'97
Group III alone " " "	June	18	"	July 4,	'97
Groups III and IV " " "	July	5	"	Aug. 26,	'97
Group IV alone " " "	Sept.	18	"	Sept. 28,	'97
Groups IV and I " " "	Oct.	4	"	date.	

The internal probable error of a single determination as derived from each group separately is as follows:

I, 0".135 II, 0".139 III, 0".137 IV, 0".142

The reduction has been kept well in hand and results are available up to August 26th. They are as follows:

$\phi = 39° 58' +$

1896	Oct. 1 – Oct. 31	IV	1".878	I	1".945	Mean	1".912
"	Nov. 1 – Nov. 27		1 .783		1 .939	"	1 .861
"	Dec. 14 – Jan. 11				2 .079	"	2 .079
1897	Jan. 23 – Feb. 16	I	2 .067	II	2 .117	"	2 .092
"	Feb. 23 – Mar. 13		2 .060		2 .231	"	2 .145
"	Mar. 16 – Apr. 20				2 .262	"	2 .262
"	May 7 – May 21	II	2. 200	III	2 .322	"	2 .261
"	May 22 – June 2		2. 202		2 .301	"	2 .251
"	June 18 – July 4				2 .246	"	2 .246
"	July 5 – July 31	III	2 .132	IV	2 .307	"	2 .220
"	Aug. 2 – Aug. 26		2. 243		2 .291	"	2 .267

Although these results are in a manner preliminary it is not likely that any great modification will follow a more elaborate discussion. The agreement with Chandler's theory is very satisfactory, except that the last two values differ somewhat more than the computed probable error would lead us to anticipate.

For the purpose of illustrating more fully the character of the work,

the individual values are given for group I, Dec. 14–Jan. 11. The third place given above is from the mean of these.

			1	2	3	4	5	6	7	8	9	10	Mean
1896	Dec.	14	2″.34	2″.25	2″.21	2″.44	2″.39	2″.30	2″.35	1″.90	2″.32	2″.28	2″.28
"	"	23	2 .05	2 .32	2 .24	2 .59	2 .23	2 .13	2 .26	2 .18	2 .47	2 .08	2 .25
"	"	24	1 .90	2 .01	1 .85	2 .33	2 .32	1 .96	2 .44	1 .83	2 .18	2 .47	2 .13
"	"	25	1 .99	1 .73	1 .77	1 .90	1 .82	1 .67	2 .00	1 .72	1 .80	1 .91	1 .83
"	"	27	2 .48	2 .19	2 .43	2 .25	2 .60	2 .56	2 .58	2 .41	1 .97	2 .03	2 .35
"	"	28	1 .85	2 .16	2 .30	1 .88	2 .06	1 .85	2 .01	2 .10	1 .94	2 .01	2 .02
"	"	31	2 .10	2 .34	....	1 .85	2 .45	2 .20	2 .23	2 .34	....	2 .15	2 .21
1897	Jan.	6	1 .87	2 .12	2 .14	2 .25	2 .09	1 .75	2 .07	2 .12	1 .72	2 .17	2 .03
"	"	7	2 .12	2 .05	2 .48	2 .28	2 .13	2 .38	2 .18	2 .15	2 .25	2 .06	2 .21
"	"	10	1 .95	1 .93	2 .30	1 .90	2 .60	2 .17	2 .54	2 .58	2 .56	2 .41	2 .29
"	"	11	1 .91	2 .25	2 .29	2 .18	1 .92	2 .47	2 .29	2 .19	2 .15	1 .96	2 .16

These values are reduced to the mean declination of the group, hence they are strictly comparable. It will be observed that the extreme range is 0″.97. The probable error of a single observation computed from this series alone is 0″.127. That of a single night's work of ten determinations is 0″.40, yet it will be noticed that with one exception every value on December 25 is smaller than that determined from the corresponding pair on the 24th, and without exception smaller than the corresponding value on the 27th, the daily means being for the 24th 2″.13, 25th 1″.83, 27th 2″.35. Thus the difference between the 25th and 27th, 0″.52, is thirteen times the probable error of an evening's determination.

Many series of zenith telescope latitudes have been examined, and in nearly every case similar anomalies have been found, in some cases the difference being much greater than the above. This seems to point unmistakably to some outside disturbing cause, presumably due to atmospheric disturbance. This will apparently be very difficult to deal with, but unless means can be found for doing so it would seem that we have about reached the limit of accuracy attainable in this class of work. C. L. DOOLITTLE.

THE WORK OF THE COLUMBIA UNIVERSITY OBSERVATORY.

At the request of the Director, Professor George E. Hale, the work carried on at the Observatory of Columbia University was described briefly by Professor J. K. Rees, the Director of the Columbia University Observatory.

Professor Rees referred to the work of the Observatory staff on (1) The Determination of the Variation of Latitude at New York City; (2) The Value of the Constant of Aberration by Küstner's Method; (3) The Reductions of the Measures of the Rutherfurd Photographs; and (4) Investigations on Polar Trail Plates.

(1) In April 1893, arrangements were concluded between the Royal Observatory at Capodimonte, Naples, of which E. Fergola is the Director, and the Observatory of Columbia University for observing the same stars with two zenith telescopes, made by Wanschaff of Berlin. These instruments have apertures of eighty millimeters and focal lengths of one meter and are in all respects exactly alike. The two latitude levels on each instrument are by Reichel of Berlin. Before leaving Berlin the instruments were tested by Dr. Albrecht. Fifty-six stars, divided into four groups of seven pairs each were observed. The investigation of the declinations of these stars was made by Professor Jacoby and Dr. Davis, and has been published as Part I, *Memoir I of the New York Academy of Sciences*. This publication is also No. 8 of the *Contributions from Columbia University Observatory*. Both Observatories have issued recently preliminary publications of the results of their work for the period May 1893 to July 1894.[1]

The following tables show the variation of latitude at the two places:

AT NEW YORK CITY.

	Date		Latitude[2]	Variation
1893	May	19,	40 48 22 .19	+ 0".00
"	June	18,	.20	.01
"	July	14.	.21	+ .02
"	Aug.	1,	.09	.10
"	Oct.	17.	.28	− .09
"	Nov.	15.	16	− .03
"	Dec.	13.	.27	· .08

[1] "The Variation of Latitude at New York and a Determination of the Constant of Aberration from Observations at the Observatory of Columbia University," by J. K. Rees, H. Jacoby, and H. S. Davis, *Astronomical Journal*, No. 401.

"Novella Determinazione della Constante dell' Aberrazione e della Latitudine di Napoli da Osservazioni fatte nel R. Osservatorio di Capodimonte negli Anni 1893 94 per E. Fergola."

[2] The Latitude Observatory is about three and one half miles north of the University Observatory.

AT NEW YORK CITY—*continued.*

Date		Longitude	Variation
1894	Jan. 18,	.18	— .01
"	Feb. 15,	.19	— .00
"	Mch. 14,	.17	— .02
"	Apr. 12,	.21	+ .02
"	May 15,	.19	— .00
"	June 13,	.13	— .06
	Mean	22.19	

AT NAPLES.

Date		Latitude	Variation
1893	May 18,	40° 51′ 45″.72	—0″.02
"	June 16,	.70	.04
"	July 16,	.70	— .04
"	Aug. 14,	.67	— .07
"	Sept. 12,	.68	— .06
"	Oct. 16,	.73	.01
"	Nov. 12,	.76	+ .02
"	Dec. 14.	.78	+ .04
1894	Jan. 17.	.74	+ .00
"	Feb. 14,	.81	+ .07
"	Mch. 14,	.75	+ .01
"	Apl. 15.	.81	+ .07
"	May 14,	.82	+ .08
"	June 13,	.78	+ .04
	Mean	45.74	

At Naples Professor Fergola observed alone. His latitude determinations depend upon 2271 pairs of stars. At New York City, the observers were Professors Rees and Jacoby and Dr. Davis. These observed 1774 pairs of stars, as follows: Rees, 809; Jacoby, 299; and Davis, 666.

Since July 1894 the observations have been continued, but on a reduced scale. Four good nights every two weeks are sought. The observations at Naples are now being made by Doctors Angelitti and Contarino, and the observations at Columbia University, by Professor Rees and Dr. Davis. Results of the later series will be ready soon for publication. In this connection it is proper to state that the complete reductions of all the observations as Part II, *Memoir I of the New York Academy of Sciences*, and No. 9 of the *Contributions from*

the Columbia University Observatory will be made with funds provided by the generous contribution of Miss Catherine W. Bruce of New York City.

(2) At New York City and at Naples, the Constant of Aberration has been determined from the first series of observations without making any assumption in regard to the law of latitude variation, either as to period or as to amplitude. The value obtained at the Columbia Observatory was 20″.46, and at the Royal Observatory at Naples 20″.53. The difference in the results seems to indicate that there is some systematic error in the method, unless some error be discovered in the computations which will bring them into better agreement. Circumstances were unusually favorable to the method, and a better agreement was to be expected. In the present state of our knowledge, we prefer to leave further conclusions to await the reductions of the later series of observations.

(3) The son of Lewis M. Rutherfurd, Rutherfurd Stuyvesant, Esq., has provided the means since his father's death for carrying on the work of the reductions of the measures of the star plates made by Rutherfurd, and also for measuring the plates unmeasured by Rutherfurd, and for reducing such measures. Mr. Stuyvesant has also provided the means for making the various publications. The work has been under the special charge of Professor Jacoby.

The Observatory has published in the *Annals of the New York Academy of Sciences*, and in its own list of *Contributions*, the following papers:

BY PROFESSOR JACOBY:

- The Rutherfurd Photographic Measures of the Group of the Pleiades. *Annals of the New York Academy of Sciences*, Vol. VI, and *Contributions from the Columbia University Observatory*, No. 3.
- The Rutherfurd Photographic Measures of the Stars about β Cygni. *Annals of the New York Academy of Sciences*, Vol. VI, and *Contributions from the Columbia University Observatory*, No. 4.
- The Parallaxes of μ and θ Cassiopeiæ, from Rutherfurd Photographic Measures. *Annals of the New York Academy of Sciences*, Vol. VIII, and *Contributions from the Columbia University Observatory*, No. 5.
- On the Reduction of Stellar Photographs, with special reference to the Astro-Photographic Catalogue Plates. On the Permanence of the Rutherfurd Photographic Plates. *Annals of the New York Academy of Sciences*, Vol. IX, and *Contributions from the Columbia University Observatory*, Nos. 10 and 11.

BY DR. H. S. DAVIS:

The Parallax of η Cassiopeiæ, deduced from the Rutherfurd Photographic Measures. *Annals of the New York Academy of Sciences*, Vol. VIII, and *Contributions from the Columbia University Observatory*, No. 6.

The Rutherfurd Photographic Measures of sixty-two stars about η Cassiopeiæ. *Annals of the New York Academy of Sciences*, Vol. VIII, and *Contributions from the Columbia University Observatory*, No. 7.

The Parallax of 61 Cygni, from the Rutherfurd Photographic Measures; the Parallax of Bradley 3077, from the Rutherfurd Photographic Measures. *Annals of the New York Academy of Sciences*, Vol. X, and *Contributions from the Columbia University Observatory*, No. 12.

All of the Rutherfurd photographs were made with wet plates. He left a number of important plates unmeasured. Before proceeding to the measurement of these plates on the Repsold machines belonging to the Observatory, the investigation on the permanence of the Rutherfurd plates was made. This investigation shows that measures can now be undertaken without any apprehension as to the movements of the collodion film.

Mr. F. Schlesinger, Fellow in Astronomy, and Mr. W. C. Kretz, University Scholar in Astronomy, are now at work measuring and reducing the plates of the Præsepe Cluster and the Cluster in Coma Berenecis.

(4) Professor Jacoby has undertaken the measurement of polar trail plates made at his request by Dr. Donner of Helsingfors. From the reduction of these measurements, he hopes to get a fundamental system of right ascensions and polar distances of the close polar stars. The method may, in the future, lead to values of the constants of precession, nutation, and aberration, which will be superior to the best meridian determinations. The results of the preliminary investigations will shortly be made public.

THE PHOTOCHRONOGRAPH.

THE instrument used at the Georgetown College Observatory for the photographic registration of star transits was devised by the Rev. George A. Fargis, S. J., and was the sequel of one devised by Professor Frank H. Bigelow of the Weather Bureau, whose first experiments had been made at Harvard with the help and suggestions of Professor Pickering. In Professor Bigelow's instrument, the photographic plate, enclosed in a holder, was moved up and down each second by an electro-magnet in a clock circuit. The motion broke up

the continuous trail, which would have been made by the star as it crossed the field, into two parallel lines of dots or dashes, each impressed on the plate during a given second of time. The reticle, which lay a little in front of the plate, was then impressed on it by throwing a light through the object glass and down the telescope, thus slightly fogging the plate except where it was covered by the wires of the reticle, which showed bright on a darkened ground. (Professor Bigelow's device was shown.)

Professor Bigelow being called away from Washington for some time, further experiments were undertaken by Father Fargis to remove what seemed to be imperfections in the first device. These were, the motion of the plate, the weight of the moving parts, the danger of parallax on account of the distance between the reticle and the plate, which was needed in order to permit the motion of the latter, and the fogging of the plate in the neighborhood of the rows of star images when photographing the reticle on the plate.

The method of doing this last was retained, as it did not seem to leave anything to be desired, if the neighborhood of the star images could be protected. Instead of spider lines a glass plate was used on which a single line was ruled. This was interrupted for a short distance in the middle of the field, so as not to interfere with the star images. The plate-holder was discarded and the bare plate used. As the plate had not to move, it was placed and held firmly almost in contact with the glass reticle. With a somewhat different arrangement it might have been quite in contact. In order to break up the star trail into portions impressed on the plate at definite times, the following arrangement was devised. A small electro-magnet had fastened to its armature at right angles a thin strip of steel, long enough to reach nearly across the field of the telescope and broad enough to cut off the cone of light from a star at a point near the focus. The whole weighed only a few ounces, the moving parts weighing only about a quarter of an ounce or less. It was carried by a clamp-ring around the draw-tube of the telescope and was placed near the reticle end, the steel finger, or shutter, stretching across the field through an opening in the draw-tube a little on the object-glass side of the reticle. The electro-magnet was in a clock circuit. (This instrument, the photochronograph, was shown.)

The action of the photochronograph may be explained by a comparison with the ordinary register of clock times or a barrel chrono-

graph. The telescope was so set that, with the armature of the electro-magnet down, the image of the star fell on the steel finger, or shutter, and was cut off from the plate. The breaking of the circuit by the clock, instead of making a signal on a sheet of paper, released the armature, causing the shutter to rise and allowing the star image to fall on the plate while the break lasted. Thus a series of impressions on the plate took the place of the ordinary register. The clock times were written on the plate instead of on the chronograph sheet and by means of the light of the star. This suggested the name given the instrument. When a sufficient number of impressions had been secured, a light was thrown through the objective and the recticle photographed directly on the time-scale, thus doing automatically what the observer does by his signals in the ordinary chronographic registry of transits. While the reticle was being photographed, the shutter was kept covering the row of star impressions, protecting this part of the field from fogging. (Some plates containing transits were shown.)

When the plate is measured in a microscope-micrometer, the time of transit over the wire can be deduced from each impression. By pairing those nearly symmetrical with the wire, in a full transit the micrometer screw-value is never needed to determine more than half an equatorial second. The screw-value itself is found from the time-scale, or row of star images. This measurement of the plate gives rise, of course, to the possibility of personal equation. Such was actually found in the Georgetown plates, arising seemingly from the use of a single wire in the micrometer. But in the photographic method, the transit is fixed on the plate, which may be measured by many persons, at any time and in any way which may be devised for eliminating personal error.

In order to test the method, the Ertel transit of the Georgetown College Observatory was fitted up and an extensive trial made. The results of this trial have been published. The following are the conclusions which are of particular interest.

As determined by the agreement *inter se* of the impressions on single plates, the probable error of a single image was $\pm 0^s.035$. Albrecht's *Hülfstafeln* give for the magnifying power of our telescope and microscope combined, at the equator, $\pm 0^s.075$ for eye and ear and $\pm 0^s.057$ for the chronograph, and the same as for the photographic method at the declinations $71^\circ.4$ and $66^\circ.0$, respectively. The breadth

in declination of the star images was usually from $3''$ to $5''$. Contrary to expectation, it was less with increasing declination.

The usual time of exposure was a tenth of a second. With this stars could be taken down to $3^m.5$, or sometimes fainter ones, though not all of $3^m.5$ could be taken. Some stars had a whole second exposure, but enough were not taken to form a judgment. The aperture of the Ertel transit is 4½ inches and its focal length 78 inches, or the ratio is 1 to 17. For several reasons, the photochronograph has been used in a series of observations for latitude by photography. With a whole second exposure, stars could ordinarily be taken as faint as the sixth visual magnitude. The zenith telescope used is better adapted to photography. Its aperture is 6 inches and its focal length 36 inches, or the ratio is 1 to 6. Such a telescope does not differ widely in weight and cost from the usual portable transit.

Obviously, one of the principal applications of the photochronograph is to the determination of longitudes. The probable error of the clock correction when at its minimum was found to be $\pm 0^s.01$. Its square at the time T, in hours from the moment of minimum probable error, was found to be $(0^s.01)^2 + (0^s.01)^2\ T^2$. The average number of stars each night which gave these probable errors was 20, including both time and azimuth stars. As there were no collimators, the method usual with portable instruments was followed, the instrument being reversed in its V's during each night's work.

JOHN T. HEDRICK, S.J.

PERSONAL EQUATION IN LONGITUDE DETERMINATIONS.

All determinations of the difference of longitude of two meridians consist of two operations, whether the method employed be that of telegraphic determination, Moon culminations, or occultations. These operations are:

(1) The determination of the local time at each station.

(2) The comparison of timepieces.

By the telegraphic method, clocks 1000 miles apart can be compared, over land lines, with practically the same accuracy as if they stood in the same room. The errors, therefore, of the longitude determination are to be found in the first of the operations mentioned, namely, in the determination of the local time.

In the star observations made at each station, every star observed will give an equation of the form.

$$\alpha - t = \Delta t + Aa + Bb + Cc - k$$

where α = R. A., t = observed time. ΔT = clock correction.
a, b, c. = azimuth, level and collimation constants respectively.
K = correction on account of daily aberration.

It is desired to determine Δt, the clock correction; with ten or twelve stars properly chosen, the effect of azimuth and collimation is completely eliminated; the correction for aberration is a small one, and is known with great exactness. The uncertainties in R.A. will not affect the agreement of results from night to night if the same list of stars is employed. There remain, therefore, only two terms in this equation whose uncertainty will cause discrepancies in the individual results. These are (1) errors in the level constant b; (2) errors in the observed time t.

I. The effect of errors in the level is probably more serious than is generally suspected. A slight pinching of the tube in the cell and the consequent change of the radius of curvature may make sudden and rather large changes. These, however, are not now under consideration.

II. The errors in t are due to accidental errors and to personal equation in observing star transits.

It is generally considered safest to exchange observers and consider the personal equation eliminated thereby. For some years past the writer has made a large number of determinations of longitude in conjunction with Mr. S. S. Gannett, of the U. S. Geological Survey. The personal equation could not be got rid of by exchanging observers. It has, therefore, been determined at the beginning and end of the season's work. The determination was made by setting up the two transits on two piers in the Observatory of Washington University, St. Louis, and determining their difference of longitude in exactly the same way that the regular longitude determinations were made, taking all possible precautions to avoid the effect of contiguity.

The following results show the probable errors of a single night's work (from the individual longitude results) for different distances. The first result is the probable error in the determination of the longitude of the two piers, which were only six feet apart.

Probable error of one night's exchange	Distance between Stations in miles	Number of Repeaters in circuit
$\pm 0^s.048$	0	0
$\pm 0\ .041$	271	0
$\pm 0\ .049$	585	1
$\pm 0\ .031$	1531	2

As these results depend upon a large number of observations, extending over six years, they may be considered as fairly indicating the relative probable errors under the different circumstances mentioned.

Two conclusions seem fairly safely shown:

In the first place, the accuracy of longitude determinations over land lines seems independent of the distances.

Secondly, the experience of the two observers seems to indicate that their relative personal equation, while fairly constant from year to year, was subject to sudden and large fluctuations from night to night, and even in the progress of a night's work.

HENRY S. PRITCHETT.

A POSSIBLE FORM OF MIRROR FOR REFLECTING TELESCOPES.

The mirror in question is a section of a paraboloid of revolution, cut at the extremity of the latus rectum. Such a mirror has the property of bringing to a single focus all the rays parallel to the axis of figure, and the axis of the reflected pencil is perpendicular to that of the incident beam: the mirror thus performing the functions of a parabolic mirror of the ordinary form and of a plane mirror placed at an angle of 45 degrees.

The advantages of this form are, *first*, that a single reflection takes the place of two; *second*, that there is no secondary mirror in the path of the incident rays. Thus the entire surface of the mirror is utilized and the image should be free from the diffraction bands caused by the support of the flat in the old style; *third*, the resulting form of equatorial mounting is extremely simple. The telescope tube becomes the declination axis, the mirror being mounted at the extremity of this axis in a manner entirely similar to that of the large flat of the Equatorial Coudé. The image formed by the mirror is therefore at the intersection of the declination and the polar axis, and remains in a constant position, no matter on what part of the heavens the telescope may be directed. This offers great advantages for the observer, and for the attachment of special appliances, such as spectroscopes. Further, no dome is required.

From experiments made at the Johns Hopkins University in grinding and polishing such a mirror, it may be safely concluded, that such a form, while extremely difficult to make, is not impossible. A small mirror has actually been constructed on these lines and is now being experimented with.

It was suggested that further experiments be carried out at the Yerkes Observatory, the facilities for glass working in the latter place being far superior to those of the Johns Hopkins. CHARLES LANE POOR.

THE SOLAR MOTION AS A GAUGE OF STELLAR DISTANCES.

1. The numerical quantity of the solar motion, expressed in units of terrestrial measure, say kilometers per second, can best be determined by measurements of the motion of stars in the line of sight. I find that Vogel's measures give a velocity of about ten kilometers per second, with a mean error of perhaps one-half its whole amount. While these measures are not sufficiently numerous to lead to a definitive result, it may be hoped that, in the not distant future, more determinations will be made.

2. The parallactic motion of a single star does not admit of absolute determination. But for groups or classes of stars situated not near the Sun-way apex or anti-apex, the motion can be determined. In my investigation of the precessional constant I found evidence that the mass of the Bradley stars of magnitude 6 and upwards near the Sun-way equator have a parallactic motion exceeding $2''$ per century, this quantity being near the limit of the motion for the stars in question.

3. From these two data it would follow, by a very simple computation, that the great mass of the Bradley stars are contained within a sphere whose surface has an annual parallax of $0''.01$.

4. In the same paper (p. 24), I found that the Bradley stars whose parallactic motion exceeds $10''$ per century probably numbered about 342. From a solar velocity of 10 kilometers per second it would follow that these stars have an annual parallax of $0''.05$ and upwards.

5. The determination of the parallactic motion of the fainter stars is among the desiderata of astronomy in the immediate future. Very valuable for this purpose would be the re-observation of the Harvard equatorial zones, found in the early volumes of the Harvard *Annals*. These have the great advantages that each star was observed twice, and that much fainter stars are included than are found in the older zones.

S. NEWCOMB.

ON THE MEANING OF THE STAR MAGNITUDES OF FATHER HAGEN'S ATLAS OF VARIABLE STARS.

As to the general plan of the Atlas Father Hagen referred to his account given a year ago at the astronomical meeting in Bamberg,

and printed in the *V. J. S.*, 31, 278. The accuracy intended in the *positions* of the stars in the Atlas will be sufficiently understood from the preface of the work, but the *magnitudes* of the stars seemed to call for an explanation.

The brightness of the stars was not estimated directly in magnitudes, but in relative steps between the stars, and the question arose how to transform these steps by computation into magnitudes.

Before answering this question it may be instructive to compare the work of this Atlas with that of a *Durchmusterung*. The purpose of the latter is to spread a uniform scale of magnitudes all over the sky, while accidental errors in the individual star magnitudes are of minor importance. In an atlas, however, which is to serve for the light variations of the stars, the relative brightness of the comparison stars is the main purpose, while a uniformity of scale between the individual charts is of little consequence. Now it is admitted by all observers of variable stars that the relative brightness of the stars is obtained with greater accuracy from steps than from magnitudes.

In transforming the steps into magnitudes the first condition must be to adapt the computed scale of magnitudes as closely as possible to some standard scale already existing. It was shown in the lecture at Williams Bay, that this condition is incompatible with a uniform lower limit of magnitude for all the charts, and that this limit varies within the magnitudes 11½ and 13½, for the Georgetown refractor of 12 inches aperture. It will be sufficient here to mention that this variation of the limit of magnitudes was referred to several causes. First, the limit of visibility in any instrument cannot be assumed to be the same for all parts of the sky and all times of the year. Then the light ratio from the brighter to the fainter stars cannot be assumed constant in any scale which was made without photometric instruments. Finally the scale itself may not be uniform for all parts of the sky.

Considering these uncertainties it was thought best to compute for each chart a step value which would bring the computed magnitudes in close agreement with a standard scale, say the Bonn *Durchmusterung*, and to apply the same to the fainter stars, without regard to the limit reached on the several charts. In using the charts and the accompanying catalogue it must then be borne in mind that the magnitudes assigned to the stars below the tenth magnitude are by no means meant to be a *continuation of the BD. scale*, but merely *the result of a computation, in which a close agreement with the BD. within the magnitudes*

7 and 10 was intended, and where the step-value thus found was applied to the fainter stars, without regard to the limit which would be thus reached.

These magnitudes fully answer the purpose for which they are intended, viz., to enable the engraver to represent on the charts the relative brightness of the stars. The observer of variable stars will thus be enabled to recognize the configuration and to identify the variable, while in his reductions and computations of the light curve and period of light variation, he will discard the magnitudes altogether. He will not even use the steps, printed in the second column of the Catalogue, except as a guide in choosing his comparison stars, because his observations will furnish him his own scale. The steps may be of use later when a photometric scale shall have been constructed for the fainter stars. It will then be an easy matter to determine, by a graphical process, the varying step-values by which our steps are adapted to this or any other new scale. A specimen chart was passed around during the lecture, and the columns of the Catalogue were represented on the blackboard. At the end of the lecture the announcement was made that Miss Catherine W. Bruce had liberally granted the indemnity for the publisher, which was necessitated by the great expense of the engraving. It was mentioned also that astronomers owe this gift to the kind commendation of Professor E. C. Pickering. These announcements were received with applause. It may be added that the I Series of the Atlas is now in print, and that the publication is in charge of Mr. F. L. Dames, Berlin (Voss-Strasse 32).

THE SYSTEM OF β LYRAE.

By G. W. Myers. (To be published in the ASTROPHYSICAL JOURNAL, January 1898.)

JOVIAN PHENOMENA.

THE planet Jupiter exhibits the greatest variety of phenomena of any planet belonging to the solar system. The surface markings may be seen with a small telescope, and from the time of Galileo to the present day the planet has been studied by astronomers, and a great number of facts have been collected regarding the changes taking place on the surface. Until within recent years it seems to have been assumed that there was no great degree of permanency in the markings.

New belts are stated to have been formed in a few hours, and in the course of a month or two the whole aspect of the disk was changed.[1]

I began a systematic study of the physical features of the planet in 1879 with the 18½-inch refractor of the Dearborn Observatory, and have continued the observations to the present time.

Very early in my study it seemed to me that the surface exhibited a much greater degree of permanency than had hitherto been admitted.

The result of eighteen years of observations shows that the changes which are continually taking place on the surface of the planet are effected in an orderly manner; some of the prominent features persisting for years with very slight changes in form or position on the disk.

The south margin of the equatorial belt and the great red spot are conspicuous examples of permanency.

In order to deduce conclusions of any value, regarding the condition of the surface of any planet, it is desirable to have a continuous record of phenomena over a long period and not isolated observations at irregular intervals.

The astronomer of today, provided with the largest telescope, and most favorable atmospheric conditions, cannot formulate a theory regarding the physical condition of a planet, which will be of any value to science, by simply noting what is seen with his telescope during one night or one opposition.

During recent years statements have occasionally been made with regard to the variation in magnitude and displacement of objects on the disk of Jupiter, which, unless properly interpreted, are misleading as to the nature of the actual phenomena.

The following considerations will elucidate the subject:

1. As the observer is looking at a rotating globe, having the axis nearly perpendicular to the line of sight, objects will cross the disk in nearly straight lines, but the linear velocity will be greatest at the equator and least in higher latitudes.

2. All objects, when they are brought in view by rotation, will be infinitely short, and as they advance farther on the disk, the apparent length will increase until the center of the object is on the middle of the disk, when it will be the longest possible; after it passes the center, the length will appear to gradually shorten until it passes behind the disk at the preceding limb.

[1] *Vide* GRANT'S *History of Physical Astronomy*, etc

3. In case a spot near the equator and one end of the great red spot happen to lie on a line parallel to the polar axis of the planet, the equatorial spot may deviate from this line $2''$ or $3''$ of arc, while under the eye of the observer; owing to the change in the length of the red spot as well as the unequal linear velocity due to difference of latitude.

From 1879 to 1884 two conspicuous equatorial white spots passed the great red spot at intervals of forty-five days, when the apparent shifting of the spots with reference to each other was well illustrated.

4. During the revolution of the planet in its orbit, all objects on the disk will be displaced in latitude, due to the elevation of the Earth above Jupiter's equator. Objects near the equator of the planet may be displaced $\pm 1''.1$ of arc, and those in higher latitudes a less amount.

5. On account of the rapid foreshortening of the degrees of latitude in the polar regions, spots or detached markings are found only in the equatorial and middle latitudes. It is seldom that a spot is seen beyond the parallel of 40°.

The parallel of 70° is at one second of arc, and that of 80° at one-quarter second of arc from the limb, hence the polar regions are entirely beyond our reach.

6. Since all markings are only seen in their normal proportions when on the central meridian of the disk, it would be a difficult matter to decide whether any actual change occurred in the shape or size of the object in its passage across the disk.

In 1880 when the red spot was most intense in color it was seen coming on the disk when the true center was at 88° from the central meridian and its computed length one second of arc.

When the spot is wholly on the disk, the true center is 71° from the central meridian and the apparent length is $3''.71$.

When the center is on the central meridian the length is $11''.61$ or 37°.6 of longitude and the breadth is $3''.6$.

In the study of the surface markings on Jupiter, the longitude, latitude and magnitude of the object has invariably been determined with the micrometer.

For all micrometer measurements, however, which are referred to a luminous disk, it is essential to employ both limbs, in order to eliminate the effect of irradiation, or what is of greater importance the enlargement of the disk due to bad definition.

The great red spot has been observed during every opposition since 1879 and its motion in longitude and latitude ascertained.

The equatorial belt and the various black and white spots have also been observed annually, except during the year 1888 when the telescope was dismounted.

The true rotation period of the planet is unknown, and hence we are unable to use a fixed zero point for longitude. Since 1879, however, the great red spot has been used as the reference point, and ephemerides have been published annually by Marth, which have been of great value for the proper reduction of observations.

The great red spot has had a gradual, but not uniform retrograde drift in longitude during the whole interval.

The rotation period of the planet, as given by the red spot, was as follows:

1879	$R = 9^h\ 55^m$	$34^s.2$
1886		39.9
1896		41.4

The spot has also drifted in latitude, the total displacement being $2''.1$ of arc.

The maximum latitude (distance from the equator) was $-7''.41$ in 1886, minimum value $-5''.32$ in 1892.

The shape and size of the spot has, however, remained nearly constant during the whole period of its visibility. It appears to be one of the most permanent features on the disk. The equatorial belt has shifted in latitude, both at the north and south margins. The belt has also changed in width, due to dissipation of the material of which it is composed, or submergence below the surface. The changes are possibly periodic during the Jovian year, due to meteorological causes. The gradual change in the size of the marking, the slow drift in longitude and latitude, show that the surface is in a plastic condition, but its exact nature is as yet unknown. The great permanency exhibited in some of the markings proves conclusively that the phenomenon is not atmospheric, as we use the term, but the medium in which the great red spot and equatorial belt are floating may have a density approximating that of a liquid.

G. W. HOUGH.

ASTRONOMICAL PHOTOGRAPHY WITH SMALL LENSES.

The photographs exhibited were made with the Willard 6-inch portrait lens during my connection with the Lick Observatory. This lens was 31 inches focus and was originally in the possession of a pho-

tographer in San Francisco, where it had been used in the early days of wet plate work, and was purchased by the Lick Observatory for a small sum. It was refigured by Brashear and in the first work (before refiguring) was strapped to the 6-inch equatorial as a guiding telescope. It was later attached to an ordinary equatorial mounting which did not permit the exposure to be carried over the meridian. A small 2-inch telescope was used to guide by when so mounted. The lens was made by Willard, New York, in 1859.

I had previously attempted to photograph the Milky Way at Nashville and at the Lick, but the lenses were not suited for that purpose. I believed that it could be done if the proper lens could be had. This large portrait lens proved to be the instrument best suited for the work, and the first photographs ever made to show the structure of the Milky Way, were secured with it in July and August of 1889.

This lens was used not only for photographing the Milky Way and the nebulæ, but also for the photography of comets and experimental work on the Earth-lit portion of the new Moon.

Description of the pictures. Several different views of the crescent Moon were thrown upon the screen, showing the Earth-lit portion of the lunar world. The details on the dark part were clearly shown with less than half a minute's exposure. These pictures showed that the solar rays after having been reflected from the Earth's surface to the Moon and thence back again to the Earth, were sufficiently strong in actinic power to give a clear and distinct picture of the Moon's surface during the lunar night.

It was suggested that a photometric study of such photographs might lead to very interesting results concerning the changing reflective power of the Earth due to the distribution of land and water and clouds as seen from the Moon at different times. It was further found that with a small "lantern lens" 1½ inches in diameter and 5⅓ inches focus, the dark part, when the Moon was a thin crescent, could be readily photographed in one second — thus showing the enormous increase of effective light-grasping power of the smaller lens over the larger one.

A photograph of the total lunar eclipse of 1895, September 3, when the Moon was near the center of the Earth's shadow, showed the Moon and its surface detail clearly and sharply defined. The exposure was seven minutes, which was much longer than necessary to show the details when in the shadow. A number of photographs, up to twenty-three minutes' exposure, were made during the eclipse with the main purpose

of a search for any possible satellite to the Moon, which might at the time be outside the shadow and thus be caught by the sensitive plate, while the light of the Moon itself was dimmed. Nothing was shown that would indicate the existence of a satellite to the Moon as bright as the eleventh or twelfth magnitude.

A photograph of the solar corona at the total eclipse of January 1, 1889, made with a $3\frac{1}{2}$-inch non-photographic telescope reduced to $1\frac{3}{4}$ inches, showed not only the details close to the Moon's limb, but also the great equatorial extensions of the corona and the beautiful symmetrical polar fans. The exposure was only $3\frac{1}{2}$ seconds. Attention was called to the fact that great care was required in the development of such a picture, to avoid the burning out of the bright details of the inner corona.

Various photographs of different portions of the Milky Way showed the remarkable structure of the galaxy. Particular attention was called to the vacant lanes and black holes and geometrical arrangements of the stars at certain points. Many portions of the Milky Way seemed to consist of thin sheetings of stars with enormous black rifts in them as if these portions were breaking up. The most remarkable of these pictures was one showing the extraordinary appearance of the sky about the great nebula of Rho Ophiuchi. The nebula (which was discovered with the Willard lens) was shown to occupy a great vacancy among the stars, from which sharply defined vacant lanes ran eastward for many degrees. This entire region seemed to be nebulous, and the smaller stars — which seemed to be of a uniform size — appeared to be actually mixed up in this nebulosity. From the fact that the nebulosity was connected also with some of the bright naked-eye stars of this region, there was good reason to believe that the smaller stars here, forming the groundwork of the Milky Way, must be really very small bodies compared with our Sun, for, from their connection with the nebula, they appeared to be at the same distance as the bright stars which were also connected with the same nebula, but which were themselves comparable in size with our own Sun.

Some of the photographs showed vast regions of the Milky Way to be involved in diffused nebulous matter; such as the regions of 15 Monocerotis, in Cepheus, in Cygnus, etc. These pictures gave the impression that the stars at those points were freely mixed up in this nebulosity without any special tendency to individual condensation which is a striking feature of the diffused nebulæ of the sky.

Many photographs of the nebulæ were exhibited — especially the exterior nebulosities of the Pleiades where streams and masses of nebulosity, connected directly with the Pleiades, were shown to exist for many degrees about the cluster.

A picture of the great curved nebula, extending over almost the entire constellation of Orion, showed what wonderful power lay in the small lantern lens for work of this class. The best exposure for this object, with this lens, seemed to be about one hour. The brighter portion of the nebula, near 56 and 60 Orionis had, however, been distinctly shown on a photograph with the Willard lens, with three hours exposure.

An enlarged photograph of the great nebula of Andromeda, showed clearly the ringlike structure of the nebula, and all the features that had been previously photographed.

Photographs of the comets of Swift, Holmes, Brooks, and Gale, showed the remarkable features of these bodies, and the extraordinary changes that utterly transformed them night after night. Brooks' comet of 1893 was perhaps the most remarkable of these bodies. Successive photographs of it showed the tail shattered and broken in a most extraordinary manner. To explain the appearances of the tail, it was suggested that some force outside that existing in the Sun and comet must have produced these malformations. Such distortions would probably be produced by the encounter of the tail with some resisting medium — such as meteor-streams or swarms, which we know exist in space. One of the pictures, which showed the tail bent abruptly at right angles, near its end, could only be explained by supposing some external force of this kind.

Among these pictures was one of the discovery of comet V 1892. A fuzzy trail was found on developing a star plate on October 12, 1892. This was suspected to be due to a comet, which was actually found upon searching for it in the sky. This comet was subsequently observed at the principal observatories of the world, and was found to be moving in an ellipse with a period of about six years. The picture is unique, as it contains the only actual discovery of a comet by photography.

A photograph of Brooks' comet on the morning of November 14, 1893, showed a fine meteor trail crossing the plate near the comet. The beginning of the trail — where the meteor first struck the atmosphere — is shown, but it passed off the plate before exploding. Three

other meteor photographs were exhibited — one of a stationary meteor. The other two pictures were of the same meteor with two different cameras, and were obtained at the Yerkes' Observatory, August 10, 1897.

The paper was concluded by the exhibition of a number of photographs of the Milky Way made with the small "lantern lens." These showed what extraordinary results could be obtained with such modest means — where the lens cost only a few dollars.

It was found that this small instrument would readily photograph in ten or fifteen minutes what it took the Willard lens from three to four hours to show. It had proved specially fine for photographing such diffused nebulosities as that connected with the great nebula of Rho Ophiuchi, which was shown by it to extend some degrees west of Antares. With this small lens the great wing-like nebula about Nu Scorpii was discovered. A sufficient number of photographs had been made with it to partially construct a map of the Milky Way, which, while showing vastly more than the eye could see, would more nearly resemble the naked eye view of the galaxy. E. E. Barnard.

RESEARCHES ON PLANET 334, CHICAGO.[1]

Planet 344 was discovered by Professor Wolf of Heidelberg, by the photographic method on August 23, 1892.[2] From two photographic observations of August 23 and 29, Mr. Berberich derived a circular orbit with a mean daily motion of 460″. At the time of the discovery the magnitude of the planet was the twelfth. Dr. Palisa of Vienna succeeded in finding the planet with the equatorial of twenty-seven inches on November 22, and up to December 8 of the same year secured altogether four observations. Two more observations were obtained from Professor Wolf's photographic plates in the months of October and November. Uniting all of these observations Mr. Berberich has derived a first set of elliptical elements which he has published in *A. N.*, 3202. In this note Mr. Berberich calls attention to the large perturbations which this planet undergoes from Jupiter. He obtains for 1893, November 10, the following perturbations of the elements:

$\delta M + 30°\ 38'\ 50''.8$	$\delta i - 0°\ 0'\ 41''.1$
$\delta\omega - 30\ 38\ 9.9$	$\delta\phi - 0\ 18\ 2''.3$
$\delta\Omega - 0\ 18\ 59''.7$	$\delta\mu - 1''.115$

[1] Provisional Report.

[2] At the astronomical conferences at Chicago, August 1893, Professor Wolf gave to the planet the name "Chicago," in memory of the World's Fair event.

Indeed the distance 334 – Jupiter becomes quite small, so small that in 1894 it decreased to 1.25 units, the radius vector of 334 being 3.90 units. The perturbing force of Jupiter compared with the attractive force $\frac{1}{1047}\left(\frac{3.90}{1.25}\right)^2 = \frac{1}{108}$. In the case of Saturn the same fraction is but $\frac{1}{250}$. During the next opposition the only observations obtained are those of Dr. Palisa on December 3, 4, 31, and January 2, 1894. Mr. Berberich has united all of the observations between 1892 and 1894 and arrives at the following set of elements:

Epoch, November 16, 1893, M. T. Berlin.

M	278	45	55".1		μ	456".3980
ω	347	34	11".3		$\log a$	0".593775
Ω	135	50	3".3	1900.0		
i	4°	33	26".9			
ϕ	0	25	14".5			

In 1897 the planet has been observed at the Algiers Observatory and seven observations were secured. (*Bull. Astr.*, September 1897, p. 360.) Professor James Hart, of Maine State College, has examined[1] the perturbations of Jupiter on the planet between November 10, 1893, and May 10, 1895, by the method of special perturbations. He has found a perturbation in μ, $\Delta\mu = 2''.841$, $\Delta\phi = -13' \, 24''.6$. The planet, therefore, very closely approaches the case where $\mu = 450''$ is fulfilled. On this account long period inequalities will become very sensible, and the planet deserves special attention first, since it comes so near to Jupiter, and second, since the mean motions of the two are nearly commensurable. The perturbing action of Jupiter will decrease the eccentricity until it becomes zero; an increase to negative values will mean a change of the perihelion by 180°. The value of $\Delta\omega = -69° \, 31'$, which Mr. Hart has found is not well enough determined and can be regarded only as an approximation. This is due to the method employed. The variation of the elements, especially those of ω and M, are so considerable that new elements should be derived after every period of forty days. This has not been done, but the same set has been retained during a year and a half. Mr. Hart's work had advanced too far before I noticed the desirability of such a change; we must therefore regard his results, so far as ω and M are concerned, as approximate only.

[1] In a thesis for M. S. at the University of Chicago.

Mr. Moulton and I have recently attempted to derive general tables for planet 334. Leverrier's method of absolute perturbations has been used, since the small eccentricity and the small inclination of the planet seemed to recommend this method in the first place. The great advantage which the smallness of e and $\eta = tg\frac{I}{2}$ presents, is somewhat counterbalanced by the greatness of the value of $\alpha = \frac{a}{a'}$, which amounts in this case to 0.7543. The coefficients of the development depend upon the expansion of $(1 + \alpha^2 - 2\alpha \cos w)^{-s} = \frac{1}{2}\Sigma L_s^{(i)} \cos iw$, where s assumes the values $\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}$. In the second volume of the *Annales de l'Observatoire de Paris*, Leverrier gives the general expressions for the $L_s^{(i)}$ quantities from $i = 0$ to $i = 15$. This limit is not exceeded in any of the larger planets, since only in the case of Venus and the Earth does α amount to 0.723, and here the mass of the perturbing planet is less than $\frac{1}{300}$ of the mass of the perturbing planet in the present case. When neglecting in the perturbations of the elements quantities $< 0''.1$ we have to go in the absolute terms to $i = 25$. The last quantity in the periodic terms will therefore be of the nature $h \cos 25\,(l' - \lambda)$. Since the coefficients are small and decrease uniformly, the additional work is not very heavy, since an extrapolation will give sufficiently accurate results in the last values. We have completed the determination of the secular perturbations including the third power of small quantities. In the periodic terms the perturbations including the second powers are nearly finished. The extension of this work from $i = 15$ to 25 is not yet done. Nor have we yet ascertained to which power of small quantities the work will have to be pushed in order to keep inside of the above mentioned limit. From the tenth volume of the *Annales* those terms have been gathered which will introduce long period inequalities: they have been extended to small quantities of the fourth order. Whereas the long period inequality of Jupiter and Saturn does not occur multiplied with the first or second power of small quantities, we find in this case, terms multiplied with the first power. Indeed, the argument of the trigonometric functions which are multiplied with the factors $\frac{1}{i\nu' - i}$, where $\nu = \frac{n'}{n}$, are $3l' - 2\lambda$ or multiples of this angle. To retain all values $> 0''.1$ in the perturbations of the elements it will probably be necessary to include the principal terms of the second

order of the mass of Jupiter and to investigate also the most important terms of the perturbing influence of Mars and Saturn.

KURT LAVES.

RESEARCHES IN SOLAR PHYSICS.

Professor Hale exhibited a number of lantern slides illustrating his solar investigations.

A PHOTOGRAPHIC MERIDIAN CIRCLE.

By F. L. O. Wadsworth. (To be published in the *Monthly Notices of the Royal Astronomical Society*.)

The following papers were presented but could not be read for lack of time.

THE WORK OF THE CATANIA ASTROPHYSICAL OBSERVATORY.[1]

The following establishments are comprised in the Observatory of Catania:

(1) Astrophysical, photographic, meteorological and seismological Observatory in the city of Catania.

(2) Astrophysical, meteorological, and seismological Observatory near the summit of Mount Etna (2950^m).

(3) Meteorological station on the south slope of Etna (1900^m).

(4) Network of thirty seismological stations in Sicily and the neighboring islands.

With a few exceptions, the various buildings and laboratories have been built and equipped under the supervision of the Director, Professor A. Riccò.

The work of the Observatory has been as follows:

1891. Restoration of the Mount Etna Observatory after its damage by the volcano. Preparation of rooms for meteorological instruments in the upper story of the Catania Observatory, and for seismological instruments in subterranean vaults. Mounting of the $5^m.50$ refractor in Catania and on Mount Etna. Investigations of the eruption of Stromboli and of the submarine eruption near Pantelleria.

1892. Beginning of daily observations and drawings of solar spots and prominences. Beginning of meteorological and seismologi-

[1] A series of photographs of the buildings and instruments of the Catania Observatory was placed on exhibition during the conferences.

cal observations. Mounting of the photographic equatorial. Observations and drawings of planets at Catania and on Mount Etna. Studies of the great eruption of Etna.

1893. Mounting of the 6-inch Cooke equatorial, and the transit instrument. Beginning of astronomical photography. Attempts to photograph the solar corona in Catania and on Mount Etna. Drawings of planets in Catania and on Mount Etna. Observations of the solar eclipse of April 23. Observations of telluric lines at Catania (50^m), Nicolosi (700^m) and Mount Etna (2950^m). Studies of Etnean earthquakes and partial eruption.

1894. Modification of the photographic equatorial. Determination of the latitude and longitude of the Catania and Mount Etna Observatories. Attempts to photograph the solar corona in Catania and on Mount Etna with Huggin's and Hale's apparatus. Photographs of the rising Sun and of clouds. Actinometric observations in Catania and on Mount Etna. Studies of the Calabrian earthquakes.

1895. Modification of the photographic equatorial. Drawings of planets. Mounting of a great seismograph (pendulum 25^m long, weighing 300^{kg}). Geophysical studies of the Æolian Islands and of the Val di Noto earthquake.

1896. Beginning made in photographing the stars of the Catania zone ($43°$), previous plates having been made for the catalogue. Drawings of planets. Cartographic studies.

1897. Mounting of photographic spectroscope. Observations of eclipses of Jupiter's satellites. Photographs of the Milky Way with a Voightländer portrait lens. Simultaneous meteorological observations on Mount Etna (1900^m station), at Nicolosi, at Catania, and on the seashore.

The solar observations are published in full in the *Memorie degli Spettroscopisti Italiani*, the observations of planets in the *Astronomische Nachrichten*, and the meteorological and seismological studies in the *Annali dell' Ufficio Centrale Meteorologico e Geodinamico di Roma*. The principal results of our work are given in the *Rendiconti della R. Accademia dei Lincei*, the *Bulletino dell' Accademia Gioenia* in Catania, or the ASTROPHYSICAL JOURNAL.

The staff of the Observatory is as follows:

Director,	Professor A. Riccò
First Assistant,	Eng. A. Mascari
Second Assistant,	Professor G. Saija

Third Assistant, - - - - - - -	Dr. E. Tringali
Mechanician, - - - - - - - - -	A. Capra
First Guardian of the Etna Observatory, - -	A. Galvagno
Second Guardian of the Etna Observatory, - -	A. Messina

Three servants and two mechanician's apprentices.

A. Riccò.

ON THE ANALYSIS OF ELECTRIC RADIATION.

In attempting to analyze electric radiation by means of the two principles used in light we must bear in mind (1) that in general we need not expect dispersion of electric rays by ordinary matter, (2) that the receiver usually influences the measured wave-length and consequently affects, apparently, the radiation. Using the principle of dispersion Garbasso and Aschkinass found, by means of a prism of glass plates upon which were pasted strips of tinfoil, that the electric radiation was dispersed and concluded that rays of electric force may be considered, not necessarily as monochromatic, but, with the same justification as in the case of light, as composite. Using the principle of interference Sarasin and de la Rive found that the wave-length measured depends on the receiver, and Zehnder that rays of electric force are analyzed by a grating into a spectrum. Both results point to a complexity of electric radiation, but Bjerknes and Poincaré point out that they may be explained on the assumption that the radiation is simple and damped.

The author used an interferometer and nail receiver to analyze the radiation from spheres. The interference curve was approximately a damped cosine curve. In interpreting this curve, if the influence of the receiver on it be not considered, the conclusion is reached that the radiation is a damped sine function of the time. But it was found, using different receivers, that the form of the curve was influenced by the receiver and therefore that the latter possessed a definite period and was not dead beat. The problem is thus more complicated than the corresponding one of light. Using a number of receivers a fair approximation regarding the nature of radiation from spheres may be arrived at and the conclusion is drawn that it is less highly damped than theory leads us to believe and that it is practically simple.

G. F. Hull.

THE PSYCHOLOGY OF THE PERSONAL EQUATION.

By Truman Henry Safford (see *Science*, November 26, 1897).

ON THE VARIATION OF SOLAR RADIATION.

By Frank W. Very (to be published in the ASTROPHYSICAL JOURNAL).

ON THE ROTATION OF THE SUN.

By L. E. Jewell.

OXYGEN IN THE SUN.

IN a note published in the ASTROPHYSICAL JOURNAL for February 1897, I gave the results of some observations made upon three lines in the solar spectrum at λ 7772.20, 7774.43 and 7775.62 which were thought by Runge and Paschen to belong to the spectrum of oxygen and also to be true solar lines.

As the result of several comparisons made between these lines and lines of the A group (due to atmospheric oxygen), on December 24, 25, 27 and 31, 1896, and on January 4, 1897, I announced that the evidence given by these comparisons seemed to be conclusive that the lines in question were of atmospheric origin, but were not due to atmospheric oxygen and were probably due to water-vapor.

A continuation of comparisons as the Sun's altitude became higher in the spring, together with the use of better absorbing media to render the extreme red end of the spectrum more easily visible, and improved methods of comparison, showed that altogether too much confidence had been placed in the early comparisons; and later the accumulating evidence indicated that the earlier observations were quite unworthy of the confidence placed in them, and that the lines in question were probably solar lines, and certainly did not vary in intensity in the same manner as the known lines of water-vapor.

The methods of comparison used were rendered necessary by the difficulties of observing in the infra-red, difficulties caused not alone by the exceeding faintness of the solar spectrum in this region, but by the very rapid change in the intensity of the spectrum at and beyond the A group. Another cause of difficulty, and probably the cause of much of the error in the earlier observations, is the overlapping ultra-violet spectrum and the presence of much diffuse light.

It was necessary to confine observations to the first spectrum because of the lack of sufficient light in the second, but nevertheless the dispersion used was very considerable. A pretty dense red glass was used, but this alone let through so much diffuse light of a red and orange

color that the spectrum in the infra-red could not be seen much beyond the A group, and not well there. Consequently a fairly dense cobalt blue glass was used, which rendered observation possible, although considerable ultra-violet light was visible, which greatly weakened the apparent intensity of lines having greater wave-length than about λ 7700 while not materially affecting the lines of the A group.

Later on it was found that a combination of cobalt blue and orange glass gave very much better results, and this was used except for the earlier observations. Still later it was found that a cobalt blue glass, used with a glass cell containing a solution of potassium bichromate or potassium chromate, gives excellent results, though another cell filled with some of the aniline dyes will probably be an improvement upon the blue glass.

The line at λ 7699.1 being the only solar line in the neighborhood of whose character I was at all confident, comparisons were mostly confined to this line and the lines of the A group.

These lines were all at some distance from the lines with which the comparisons were made, thus rendering the comparisons difficult as well as somewhat uncertain; particularly upon days when the infra-red spectrum was weak or when the overlapping ultra-violet was exceptionally strong. But it was the only method available under the circumstances.

Considerable reliance was at first placed upon the circumstance that although the three lines forming the triplet observed were difficult to see near noon, yet they were scarcely more difficult to see near sunset. On some days they were certainly rather more prominent at this time, and on particularly clear days late last December were seen when the Sun was within a degree or two of the horizon.

It is now evident that this apparent increase in intensity was due to the effect of the overlapping ultra-violet light in diminishing the apparent blackness or intensity of the lines in the infra-red at the noon observations. This must have been particularly true upon clear cold days, while the atmospheric absoption of ultra-violet light would render these lines more distinct with the Sun at a less altitude. This is probably also the reason why these lines seemed to be considerably stronger upon the warm moist days of December 31 and January 4.

After the orange glass was used these differences ceased to be observed, or at least were not so evident.

The observing method used was to compare the intensity of the

lines under consideration with the lines in the A group, which were most nearly of the same intensity. Some comparisons were also made with the solar line at 7699.1, but they were not satisfactory. However, indirect comparisons were satisfactorily made by comparing this line with the lines of the A group at different altitudes of the Sun.

These observations have been reduced, and though they are not particularly accurate individually, and not always as consistent as could be desired, yet the means of the observations, at different altitudes of the Sun, conform fairly well to a curve which represents the change in the relative intensity of a solar line when compared with the lines of the A group. The change in intensity of these lines with change in the altitude of the Sun is readily determined from the results of observations made during 1892 and 1893.[1]

Attempts have been made upon various occasions to test the solar origin of these lines by observing their positions at the east and west limbs of the Sun, but the seeing has never been good enough to make satisfactory settings of the cross hairs when the edge of the Sun was upon the slit. Several attempts have also been made to determine whether the lines were affected over a Sun-spot or not. But I could never detect any difference between their behavior and that of lines of the A group (which are due to atmospheric oxygen). The seeing was never sufficiently good in the extreme infra-red to permit the detecion of any slight differences, if any existed.

In a recent paper in *Wiedemann's Annalen*, Professor Runge gives the wave-lengths and relative intensities of numerous lines of oxygen, two triplets of which he considers to be present in the solar spectrum.

I have recently carefully examined the lines in the beginning of the ultra-violet which he has assigned to oxygen. The lines are of true solar origin and the coincidence and relative intensities in the solar and oxygen spectrum agree fairly well for the lines 3947.50 and 3947.78.

If the wave-lengths of the oxygen lines given be not considered very exact and the first and last lines of the triplet be considered to be the same as the solar lines, then the middle line could be placed at the red edge of the solar line at 3947.675, when the appearance of the triplet would be quite similar to the one in the infra-red.

The solar line at 3947.675 (which is due to iron) shows, however, no signs of duplicity or shading at the red edge.

[1] This JOURNAL, 5, 324.

The other two solar lines are considerably weakened and somewhat broadened at the Sun's limb, an indication that the origin of the lines is at a considerable depth in the solar atmosphere. There is no difference between the appearance of these lines and that of the smallest metallic lines. LEWIS E. JEWELL.

LARGE MAGELLANIC CLOUD.[1]

STARS whose spectra are of the fifth type consisting mainly of bright lines have hitherto been found only near the central line of the Milky Way. Of the 67 stars of this type so far discovered the average deviation from this line is 2 39′. For only one object, whose distance is 17° 39′, does the deviation exceed 9°. It is difficult to explain this very close approach to a great circle, as these stars fall in a band much narrower than the Milky Way itself. This law of distribution is one of the most important results attained by means of the Henry Draper Memorial. The two Magellanic Clouds closely resemble the Milky Way in appearance, although completely detached from it, and distant from its central line by about 33° and 45° respectively. From an examination of the photographs of the spectra of the stars in the large Magellanic Cloud, recently taken with the Bruce photographic telescope, Mrs. Fleming has discovered six stars whose spectra are of the fifth type; also that bright hydrogen lines are present in the spectra of seven stars of the first type, and that the spectra of six known nebulæ are gaseous and not continuous. The power of the instrument and the quality of the photographs are shown by the fact that, with one exception, all of these stars are so faint that they have not been included in any of the star catalogues as yet published. A list of these objects is given in the following table. The successive columns contain the approximate right ascensions and declinations for 1900, the galactic longitudes and latitudes of the nebulæ and stars of the fifth type, and a brief description of the objects.

The fifth star is variable and has a range of rather more than one magnitude. It is identical with Gilliss No. 3092.

The tenth object is identical with the second object, announced as a gaseous nebula, in *Circular* No. 17. Small gaseous nebulæ and faint fifth type stars can be distinguished photographically only by the wavelength of the principal line in their spectra. Accordingly, on the

[1] *Harvard College Observatory Circular* No. 19.

R. A. 1900	Dec. 1900	Gal. long.	Gal. lat.	Description
h m				
4 54.6	−69 21′	247 14	35 16	Gaseous nebula. *N. G. C.* 1743.
4 56.4	66 37	243 54	−35 44	Type V. Brightest star in *N. G. C.* 1761.
4 56.5	−66 34	243 51	−35 44	Gaseous nebula. *N. G. C.* 1763.
5 14.0	−67 34	. . . . .	. . . .	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright. In *N. G. C.* 1871.
5 18.9	−69 21	. . . . .	. . . .	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright. Variable. In *N. G. C.* 1910.
5 20.1	69 45	247 10	33 1	Type V. In *N. G. C.* 1918.
5 25.6	68 33	. . . . .	. . . .	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright. In *N. G. C.* 1849.
5 30.4	67 30	244 24	−32 20	Type V.
5 32.0	71 6	248 37	31 51	Type V.
5 35.2	69 49	247 5	31 43	Type V.
5 35.6	67 39	244 32	−31 50	Gaseous nebula. *N. G. C.* 2029.
5 37.2	−69 26	. . . . .	. . . .	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright. In *N. G. C.* 2050.
5 39.3	69 8	246 15	31 24	Gaseous nebula. *N. G. C.* 2070. 30 Doradus.
5 39.5	69 5	246 11	31 23	Type V.
5 40.6	−69 49	247 2	−31 15	Gaseous nebula. *N. G. C.* 2079.
5 40.6	69 42	. . . . .	. . . .	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright. In *N. G. C.* 2080.
5 40.6	69 42	. . . . .	. . . .	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright. In *N. G. C.* 2080.
5 40.7	−69 27	246 37	31 16	Gaseous nebula. In *N. G. C.* 2081.
5 41.0	−69 26	. . . . .	. . . .	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright. In *N. G. C.* 2081.

Bache plates the bright line was assumed to be due to a gaseous nebula and was identified with a faint adjacent star. Two Bruce plates show that the spectrum is that of a fifth type star following $0^m.1$, north $3'$.

The gaseous character of the nebulosity surrounding 30 Doradus is well known. These photographs show that several objects closely adjacent to it have bright lines in their spectra.

After the above description had been prepared a letter was received from Peru, from which it appeared that the presence of bright lines in the spectra of several of these stars had already been found by Dr. Stewart at Arequipa. His description of each object is given below preceded by its right ascension:

R. A. $4^h\ 54^m.6$. Four bright lines including $H\beta$, $H\gamma$, and $H\delta$.

R. A. $5^h\ 14^m.0$. $H\beta$ and $H\gamma$ bright.

R. A. $5^h\ 18^m.9$. $H\beta$, $H\gamma$, and $H\delta$ bright.

R. A. $5^h\ 20^m.1$. $H\beta$ bright and broad.

R. A. $5^h\ 25^m.6$. *Hβ* somewhat bright, not intense.

R. A. $5^h\ 32^m.0$. *Hβ* somewhat bright, broad, not intense.

R. A. $5^h\ 35^m.2$. *Hβ* bright and broad, partial spectrum only visible.

R. A. $5^h\ 37^m.2$. *Hβ*, *Hγ*, and *Hδ* bright.

R. A. $5^h\ 39^m.3$. *Hβ* and *Hδ* bright.

R. A. $5^h\ 40^m.6$ (first). *Hβ* bright and broad.

R. A. $5^h\ 40^m.6$ (second or third). *Hβ*, *Hγ*, and *Hδ* bright and broad.

R. A. $5^h\ 41^m.0$. *Hβ*. *Hγ*, and *Hδ* bright and sharp.

The line called *Hβ* by Dr. Stewart in the first, ninth, and tenth of these objects is probably the line 5007, characteristic of gaseous nebulæ. The line called *Hβ* in the fourth, sixth, and seventh objects is probably the line 4688, characteristic of spectra of the fifth type.

September 28, 1897. EDWARD C. PICKERING.

SPECTRUM OF A METEOR.[1]

THE photographs of the spectra of the stars taken at the Harvard College Observatory as part of the Henry Draper Memorial differ in two respects from those ordinarily taken elsewhere. Instead of using a spectroscope with a slit, in which but one star is photographed at a time, a large prism is placed over the object-glass of the telescope and thus spectra of all the bright stars in the field of view are obtained. The number of stars photographed simultaneously is still further increased by substituting for the object glass a portrait lens like that used by photographers, only larger. The field of view is in this way increased from two degrees square to ten degrees square, and a photograph is obtained of the spectra of all the brighter stars in this large region. Many thousand plates covering the entire sky, have been taken in this way at the Cambridge and Arequipa Stations of this Observatory. All have been examined by Mrs. Fleming and, as a result, numerous remarkable objects have been discovered. One of the latest is the spectrum of a meteor which has thus been photographed for the first time. Since it is impossible to foresee when the bright meteors will appear, or what path they will follow, a photograph will be obtained only when one happens to cross the field of the telescope. A number of trails of meteors have been obtained, both here and elsewhere, when charts of the stars were photographed, no prism being

[1] *Harvard College Observatory Circular* No. 20.

used. When the prism was in place no meteor bright enough to leave a noticeable trail has heretofore been photographed on the many thousand plates examined. At about 11:00 P.M. on June 18, 1897, however, when the 8-inch Bache telescope at Arequipa was directed toward the constellation Telescopium, a bright meteor appeared in right ascension $18^h\ 19^m$, declination $47°\ 10'$, and passed out of the field at right ascension $18^h\ 29^m$, declination $-50°\ 30'$. The spectrum consists of six bright lines whose intensity varies in different portions of the photograph, thereby showing that the light of the meteor changed as its image passed across the plate. The approximate wave-lengths of these lines are 3954, 4121, 4195, 4344, 4636, and 4857, and their intensities are estimated as 40, 100, 2, 13, 10, and 10, respectively. The first, second, fourth, and sixth of these lines are probably identical with the hydrogen lines $H\epsilon$, $H\delta$, $H\gamma$, and $H\beta$, whose wave-lengths are 3970, 4101, 4341, and 4862. The fifth line is probably identical with the band at wave-length 4633, present in spectra of stars of the fifth type and forming the distinctive feature of the third class of these stars. The third line, which is barely visible, is perhaps identical with the band at wave length 4200, contained in these stars. (*A. N.* **127**, 1).

It will be noticed that of the four hydrogen lines in the spectrum of the meteor, $H\delta$ is the most intense. This is also the case in the spectrum of *o* Ceti and of many other variable stars of long period. In some variables of long period $H\delta$ and $H\gamma$ are equally intense, while in others $H\gamma$ is the more intense. In some stars of the first type in which the hydrogen lines are bright, like γ Cassiopeiae, the line $H\beta$ is much more intense in the photographic spectrum than any of the other lines, while in the spectra of stars like P Cygni and η Carinae, $H\delta$, $H\gamma$ and $H\beta$ are nearly equally bright. These results show an important resemblance between meteors and stars having bright lines in their spectra, and may aid in determining the conditions of temperature and pressure in these bodies. Since bright meteors sometimes appear during the November meteoric shower a special effort will be made here to obtain photographs of them, both trails and spectra, on November 13.

November 8, 1897. EDWARD C. PICKERING.

LOSS OF LIBRARY BY FIRE.

ON September 14, 1897, at 1:30 A.M., the Grand Canyon Hotel in Flagstaff was discovered to be on fire, and within twenty minutes from

the first alarm the entire building was in flames. Owing to the headway already made before the alarm was given, and the insufficiency of the water supply, and the consequent weakness of the fire department, all hope of saving the contents of the building was at once given up. In this hotel had been the office of Mr. Cogshall and myself ever since the beginning of our work with the Lowell Observatory, August 1, 1896: and our apartments contained all the mathematical, astronomical, physical and other books which I had brought with me from Chicago, or since purchased; besides various precious papers, letters, manuscripts, pictures, etc., and the records of our work on the double stars of the southern hemisphere. The night being unfavorable for observations we had retired; and in the hurried moments of darkness and confusion attending the evacuation of the burning building, we were barely able to save the records of the Observatory, the general manuscript catalogue of all double stars within 75° of the south pole, and a few other works such as the *Mecanique Celeste*—everything else, the library of books, the manuscripts, letters, pictures, personal effects being a total loss.

As this destruction of the library will necessitate the formation of a new one, I beg to state that I am desirous of restoring first the astronomical works relating to the double stars of the southern hemisphere. If friends or other men of science with whom I have exchanged publications should have copies or reprints of their works which they would feel disposed to offer, I need hardly add that they would prove very useful and be received with grateful appreciation.

LOWELL OBSERVATORY, T. J. J. SEE.
Flagstaff, Arizona, September 16, 1897.

A NOTE ON THE THEORY OF TELESCOPIC IMAGES.

I HAVE just discovered an important error in the result, for the focal plane illumination due to an infinitely extended source, which was first obtained by LORD RAYLEIGH and STRUVE, and which has recently been used by the writer in developing the theory of the contrasting or delineating power of telescope objectives. This error does not affect, to any degree, the conclusions reached, so far as *practical photographic contrast* is concerned. A paper containing full details will appear in the next number of the JOURNAL. F. L. O. WADSWORTH.

YERKES OBSERVATORY,
December 16, 1897.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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